SAND REPORT

SAND2002-3737
Unlimited Release
Printed November 2002

Regional Dynamic Simulation Modeling and Analysis of Integrated Energy Futures

Leonard A. Malczynski, Walt Beyeler, Stephen Conrad, David Harris, Paul Rexroth, and Arnold B. Baker

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94-AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.doe.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2002-3737
Unlimited Release
Printed November 2002

Regional Dynamic Simulation Modeling and Analysis of Integrated Energy Futures

Leonard A. Malczynski, Office of Chief Economist
Walt Beyeler, Critical Infrastructure Surety
Stephen Conrad, Critical Infrastructure Surety
David Harris, Networked Systems Survival and Assurance
Paul Rexroth, Defense Nuclear Materials Stewardship
Arnold B. Baker, Chief Economist

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185

Abstract

The Global Energy Futures Model (GEFM) is a demand-based, gross domestic product (GDP)-driven, dynamic simulation tool that provides an integrated framework to model key aspects of energy, nuclear-materials storage and disposition, environmental effluents from fossil and non fossil energy and global nuclear-materials management. Based entirely on public source data, it links oil, natural gas, coal, nuclear and renewable energy dynamically to greenhouse-gas emissions and 12 other measures of environmental impact. It includes historical data from 1990 to 2000, is benchmarked to the DOE/EIA/IEO 2001 [5] Reference Case for 2000 to 2020, and extrapolates energy demand through the year 2050.

The GEFM is globally integrated, and breaks out five regions of the world: United States of America (USA), the Peoples Republic of China (China), the former Soviet Union (FSU), the Organization for Economic Cooperation and Development (OECD) nations excluding the USA (other industrialized countries), and the rest of the world (ROW) (essentially the developing world).

The GEFM allows the user to examine a very wide range of "what if" scenarios through 2050 and to view the potential effects across widely dispersed, but interrelated areas. The authors believe that this high-level learning tool will help to stimulate public policy debate on energy, environment, economic and national security issues.

Acknowledgments

Arnold Baker served as the project Principal Investigator. Len Malczynski served as the FY 2002 Project Manager; Nate Bixler served as Project Manager for FY 2000-2001, and a team member in FY 2002. Len Malczynski also served as the technical lead on overall model integration, with Dave Harris, and the technical lead on the energy and greenhouse gas module. Steve Conrad served as the technical lead for the back-end module, Paul Rexroth for the weapons module and Walt Beyeler for the environmental module. Gregg Mann served as a team member during FY 2000-2001.

The team would like to acknowledge the support of and input from Bob Eagan and Roger Hagengruber, Tom Blejwas, Margaret Chu, Peter Davies, Dennis Berry, Dori Ellis and Terri Olascoaga. It also would like to thank the Cooperative Monitoring Center for hosting a model review meeting for an earlier model version. Any errors and omissions remain the responsibility of the team.

Table of Contents

List of Figures

List of Tables

1. Overview

The GEFM is divided into five regional segments: the USA, China, the FSU, OECD countries (excluding the USA), and the ROW (essentially the developing world). Thus the model allows for regional as well as global examination and evaluation of energy demand, nuclear materials, environmental impacts, and proliferation risk.

The Energy Module is GDP driven, with historical data and predicted GDP growth rates forming the basis for this module. GDP is converted to energy demand via energy intensities, i.e., the energy required to generate a unit of GDP. Base projections for GDP growth and energy intensities are contained in the module, but can be adjusted by users. Likewise, historical and predicted energy shares are used to estimate the fractions of overall energy demand supplied by various energy sources, including oil, natural gas, coal, renewables, and nuclear energy. Base values for energy shares also can be modified by users. Data sources for this module are from the International Energy Outlook (IEA) [1-4] and from the EIA [5] The Energy Module drives the Fuel Cycle Front-End Module through demand for nuclear energy. Energy requirements by fuel type also affect estimates of environmental impacts, as illustrated in Figure 1.

Demand for nuclear energy results in uranium mining, chemical processing to purify the uranium, enriching the uranium, and fabrication of fuel. The flow of materials through these processing steps are tracked by the Fuel Cycle Front-End Module. Alternatively, reprocessed fuel can be fed back from the fuel cycle back end to the front end, as indicated in Figure 1. The nuclear material origin for reprocessing can be from spent fuel or defense nuclear materials. Nuclear energy demand is further broken down into energy demand by reactor type. Since fuel-cycle requirements differ by reactor type, this affects the front-end processing and, potentially, the back-end reprocessing. The reactor types considered in this module are the:

- Light-water reactor (LWR),
- CANDU reactor,
- Graphite-moderated reactor [*reactor bol'shoy mozhnosti kanal'nyye* (RBMK) Chernobyl design],
- Conventional gas-cooled reactor,
- Generation IV reactor (Gen. IV), and
- High-temperature gas-cooled reactor (HTGR) used solely to generate hydrogen, which is assumed to be used to fuel transportation.

Energy options in the model include forward-looking alternative technologies, such as:

- Generation IV nuclear reactors, and
- Production and use of hydrogen as a transportation fuel.

These alternative technologies--likely to be realized before the year 2050--are modeled to facilitate the exploration and evaluation of future policy issues as well as research investments.

Back-end decisions, such as whether or not to reprocess spent fuel or surplus weapons materials, affect the material flows through the front end of the nuclear fuel cycle. These decisions, in turn, affect environmental impacts and the risk of nuclear proliferation. All of these interconnections are shown schematically in Figure 1.

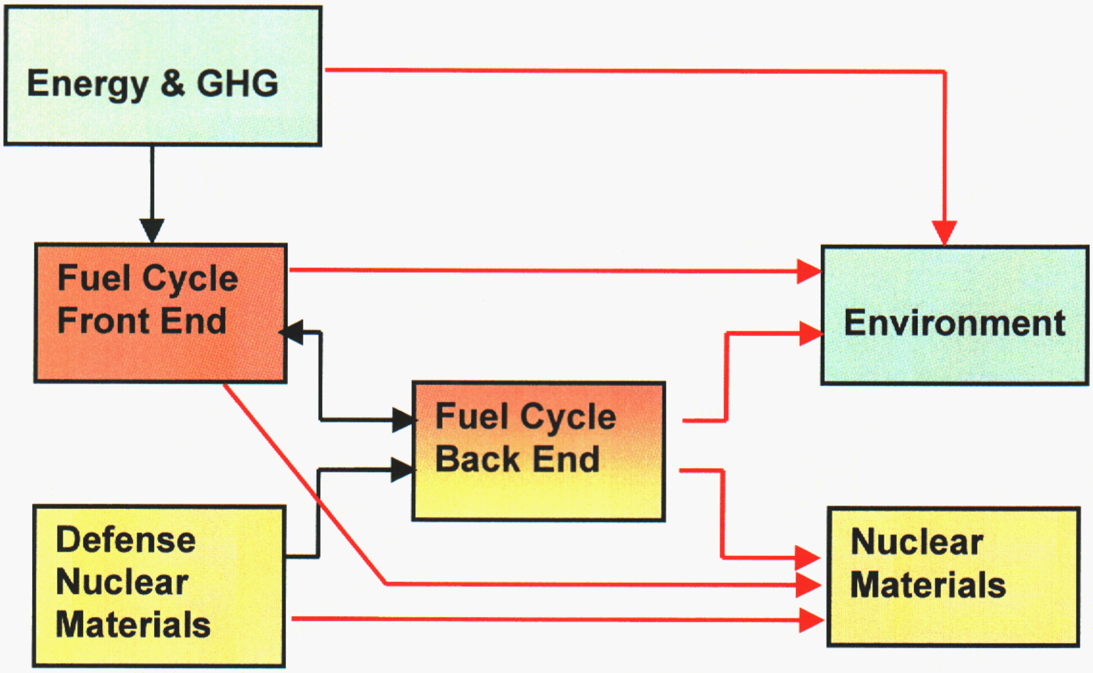

Figure 1. Schematic Diagram of the Interrelationship between the Modules of the Global Energy Futures Model.

The modules are as follows:

- Fuel Cycle Back-End Module,
- Energy Module,
- Fuel Cycle Front-End Module,
- Defense Nuclear Materials Module, and
- Environmental Module.

A. Fuel Cycle Back-End Module

The Fuel Cycle Back-End Module allows numerous options to be considered, including reprocessing spent fuel and converting defense nuclear materials into uranium or mixed-oxide fuels. Options also include spent-fuel disposition (such as permanent underground disposal, monitored retrievable storage, and storage at reactor sites) and reprocessing, assuming that uranium and plutonium are reused, and fission products vitrified.

This module's base case presumes that current plans for each region of the world are implemented. For example, the Yucca Mountain repository is scheduled to open in 2010, with repositories in a number of other countries to follow. France and Japan currently reprocess nuclear fuel and Russia intends to in the future. Thus, all these current expectations are implemented in the base case.

Flows of materials into the Fuel Cycle Back-End Module are from the Fuel Cycle Front-End and Defense Nuclear Materials Modules, Figure 1. Materials also will flow from the Back-End Module into the Front-End Module when reprocessing is considered. Options selected in the Back-End Module influence estimates of environmental impacts and the potential for nuclear proliferation.

B. Energy and Green House Gas Emissions Module

This module drives the GEFM. It includes the historical and predicted GDP, energy intensity and energy efficiency data from which energy consumption is derived. This module is the basis for energy consumption growth and the relative consumption of fuel shares in each of the economic sectors.

C. Fuel Cycle Front-End Module

The Gen. IV, which is used solely for electricity generation, also can be defined to be a HTGR. The HTGR and Gen. IV reactor types allow users to explore futuristic options in which a primary goal might be, e.g., to reduce carbon emissions or spent fuel.

The base case for this module assumes that the types of reactors currently employed in each region of the world are maintained into the future. Thus, the fractions of HTGR and Gen. IV reactors are zero through 2050 in the base case. Various environmental pollutants are created during uranium-ore processing to form nuclear fuel. Information from the fuel cycle front end is transferred to the environmental module to estimate environmental impacts. Furthermore, some of the materials consumed and created as a result of nuclear-energy production affect the potential for nuclear proliferation.

D. Defense Nuclear Materials Module

The Defense Nuclear Materials Module translates decisions to increase or decrease the number of weapons within each region of the world into quantities of nuclear materials that can fuel energy. The material flow is via the Fuel Cycle Back-End Module, where these materials are either processed into nuclear fuel or vitrified for disposal. Since most of the world's supply of defense nuclear materials is either in the USA or the FSU, these regions have the most potential to affect nuclear energy via defense materials. Modeling choices in this module (e.g., whether to reduce nuclear stockpiles) directly affect the potential for nuclear proliferation as well as nuclear-cycle models.

E. Environmental Module

The Environmental Module characterizes the environmental impact of selected energy options. All energy sources have some impact on the environment, but to a large extent they differ by energy source. For example, energy derived from fossil-fuel combustion affects the environment through release of carbon (primarily in the form of CO_2 define) and other pollutants into the atmosphere. Extraction or mining of fossil fuels also impacts land and water. Both mining and coal combustion also release radioactive materials, primarily radon, into the atmosphere.

The Environmental Module provides measures of 14 environmental impacts. Six of these are atmospheric emissions:

- Carbon (primarily as CO_2),
- Methane,
- Particulates,
- NO define,
- SO_2 define, and
- Volatile organic compounds (VOCs).

Less volatile effluents include mercury and ash sludge. A third category of environmental impact is radioactivity, which includes both volatiles and condensed-phase materials. Finally, the module also estimates environmental impacts related to water consumption, water impacts, land required for facilities, land impacts, and fuel consumption. Water and land are impacted by mining operations as well as fuel processing and energy production.

F. Optional User Inputs

The second part of the input involves assigning quantitative measures regarding the desirability of the above materials to the potential proliferator. This may differ qualitatively from the order suggested above. One concept is to base these measures on cost estimates to convert each material type into a functional weapon. These are categorized by module, as outlined in the preceding sections. All input values have assigned defaults that need not be adjusted—allowing users to explore only those input variables of specific interest to the user.

1) Optional Fuel Cycle Front-end Inputs

Optional inputs to the Fuel Cycle Front-End Module include the:

- Characteristics of the fuel cycle by reactor type (independent of region),
- Characteristics of uranium processing (uniform throughout the world), and
- Shares of reactor types in each region.

2) Optional Energy and Greenhouse Gas Emissions Module Inputs

Optional input to the Energy Module allows users to modify;

- Economic growth rates by Region,
- Energy intensity for each three sectors (industry, transportation, and other) and energy efficiency for electricity in each region, and
- Fuel shares for each sector in each region. (The fuel shares modeled are coal, natural gas, oil, nuclear, and renewables.)

3) Optional Fuel Cycle Back-End Inputs

The Fuel Cycle Back-End Module allows users to specify the:

- Fraction of spent fuel to be reprocessed in each region,
- Parameters affecting the processing of excess weapons plutonium into MOX,
- Parameters affecting the vitrification of excess weapons plutonium,
- Capacity and timing of disposal of high-level waste in repositories,
- Capacity and timing of monitored retrievable storage, and
- Quantity and timing of anticipated transfers of spent fuel from the OECD nations to the FSU as well as plutonium transfers from the FSU to the USA.

4) Optional Environmental Inputs

The Environmental Module includes options to:

- Select the extent of environmental impacts on a scale that ranges from optimistic to pessimistic,
- Choose the allocation of renewable energy sources for each region, and
- Define the types of impacts to be investigated.

The types of renewable energy sources modeled are hydro, wind, solar, and combustibles.

Environmental impacts results can be displayed by region or for the entire world. The regional results have an added feature summing up regions if more than one region is selected. Environmental impacts for the world are shown for each of the five regions plus the world, resulting in six curves for each calculation. Environmental-impact options must be selected as an input before a run is performed.

5) Optional Weapons Inputs

Weapons input parameters include:

- Weapons-production capacity for each region,
- Mass of plutonium and HEU needed for a weapon, and
- Initial inventories of weapons-grade plutonium.

The inputs also allow users to schedule reductions or increases in nuclear weapons stockpiles in each of the following categories: active, in reserve, and dismantled. Choices to reduce weapons stockpiles can result in the flow of materials into the Fuel Cycle Back-End Module.

6) Optional Weapons Material Inputs

The weapons materials considered are:

- Pits,
- Excess HEU,
- Weapons-grade plutonium, and
- Weapons-grade plutonium that has been converted into MOX.

G. Results

Results are presented for a 60-year period: 10-years (1991 to 2000) historical, 20-year forecasts (2001 to 2020) and 30 year extrapolation (2021 to 2050). Clicking on the "Run" button shown in the upper left corner of Figure 2 starts the model. Alternatively, users can move forward by one or 10 years at a time using the second or fourth buttons shown in Figure 2. User options can be adjusted any time during the run to allow for time-varying input values.

During a run or after its completion, results can be displayed using the "World Summary", "World Results", or "Regional Results" buttons. The following results are accessed from the World Summary option. These results use all of the default options.

Figure 3 shows the historical and predicted world-fuel demand with coal (red), oil (green), natural gas (blue), other fuels (brown) and nuclear (purple). In the base case, oil maintains its position as the dominant fuel source, largely because of its contribution to the transportation sector. In this assumption, oil continues to be plentiful so demand is unconstrained by supply. Initially, coal is second in dominance, but overtaken by natural gas by 2010. Other fuel sources category, primarily composed of renewables, is dominated by hydro and holds a solid fourth place. Then, nuclear energy increases slightly over the 60-year period (1990-2050), but substantially loses its share of energy production under the base case assumptions. These assumptions use EIA predictions for fuel shares out to 2020 and extrapolations of these predictions beyond 2020.

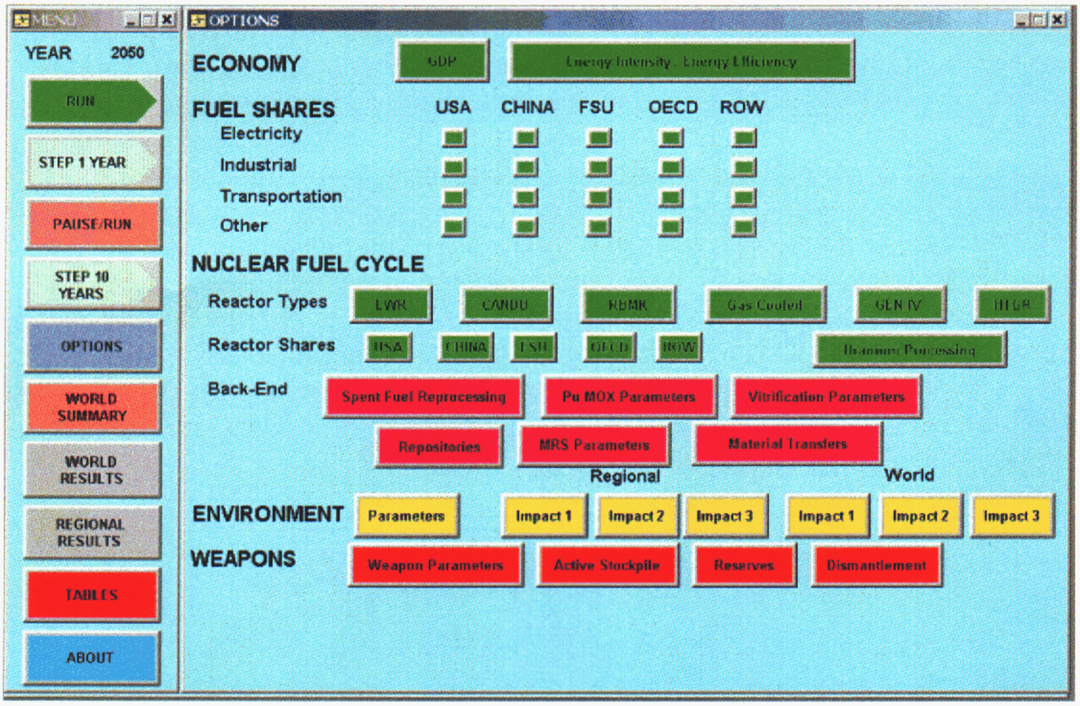

Figure 2. Screen Showing the Range of Optional Inputs to the Global Energy Futures Model.

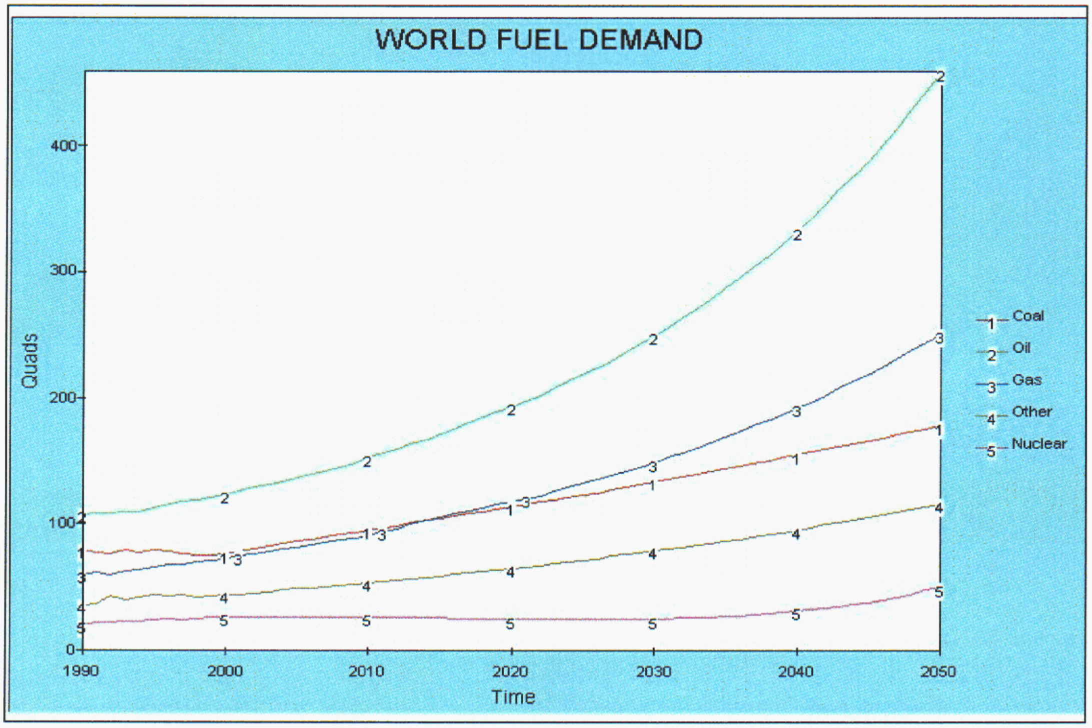

Figure 3. Historical and Extrapolated Annual World Energy Demand (Quadrillion BTUs) by Fuel Type.

Figure 4 shows the accumulation of world wide spent fuel from nuclear-power generation for the base case with local storage (red), monitored retrievable storage (green), and waste repositories (blue). Most nuclear fuel in this scenario is stored within plant boundaries of each nuclear-power station. Monitored retrievable storage is not assumed to contribute because no country has announced it will build such a facility. All of the underground disposal facilities scheduled to go online are predicted to reach capacity by the year 2045. However, this planned capacity is inadequate to store the quantity of nuclear fuel generated over that time. In fact, less that one-third of the projected spent fuel could be stored in all of the currently planned waste repositories. If significant number of nations decide to scale up nuclear-energy production to diminish carbon emissions, the need for a solution to nuclear waste would be even more acute--pointing to a need for more repositories or spent-fuel reprocessing facilities on a larger scale than would otherwise be needed for the few countries that now or soon will have this capability.

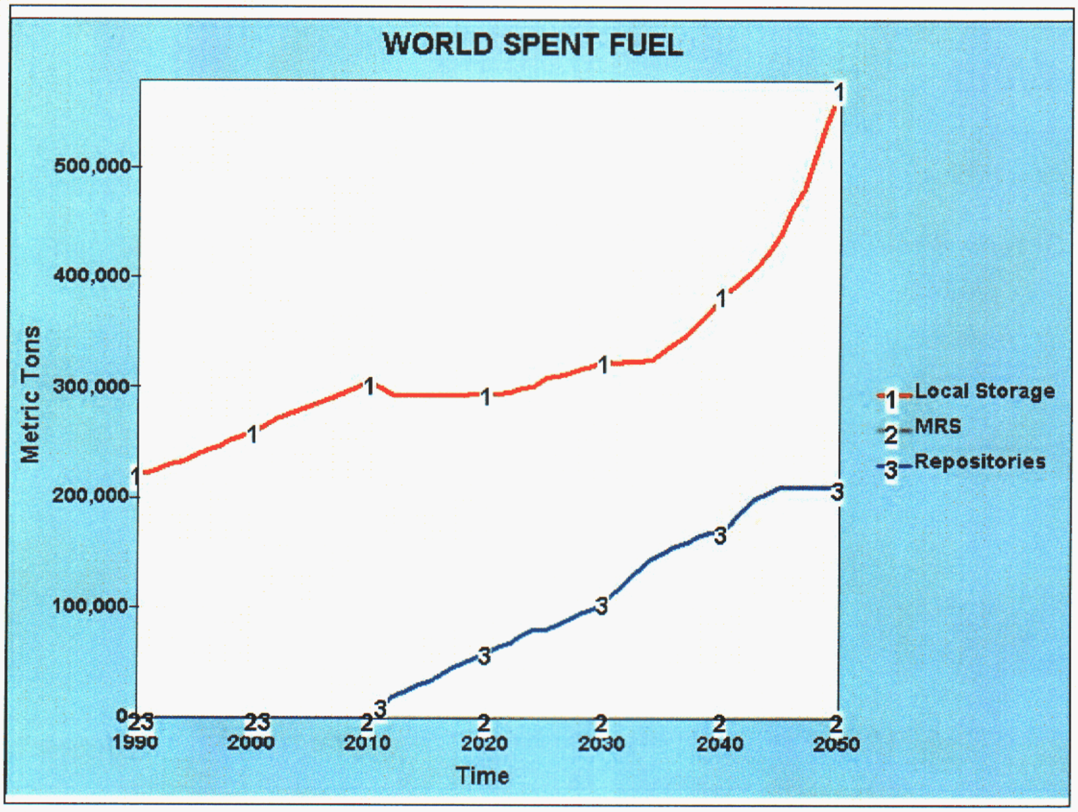

Figure 4. Historical and Extrapolated Accumulated World Spent Fuel (Metric Tons).

Figure 5 shows carbon-emission forecasts that correspond to the energy demand shown in Figure 3. If nothing is done to curb carbon emissions, the annual rate of carbon emissions is expected to triple between 1990 and 2050.

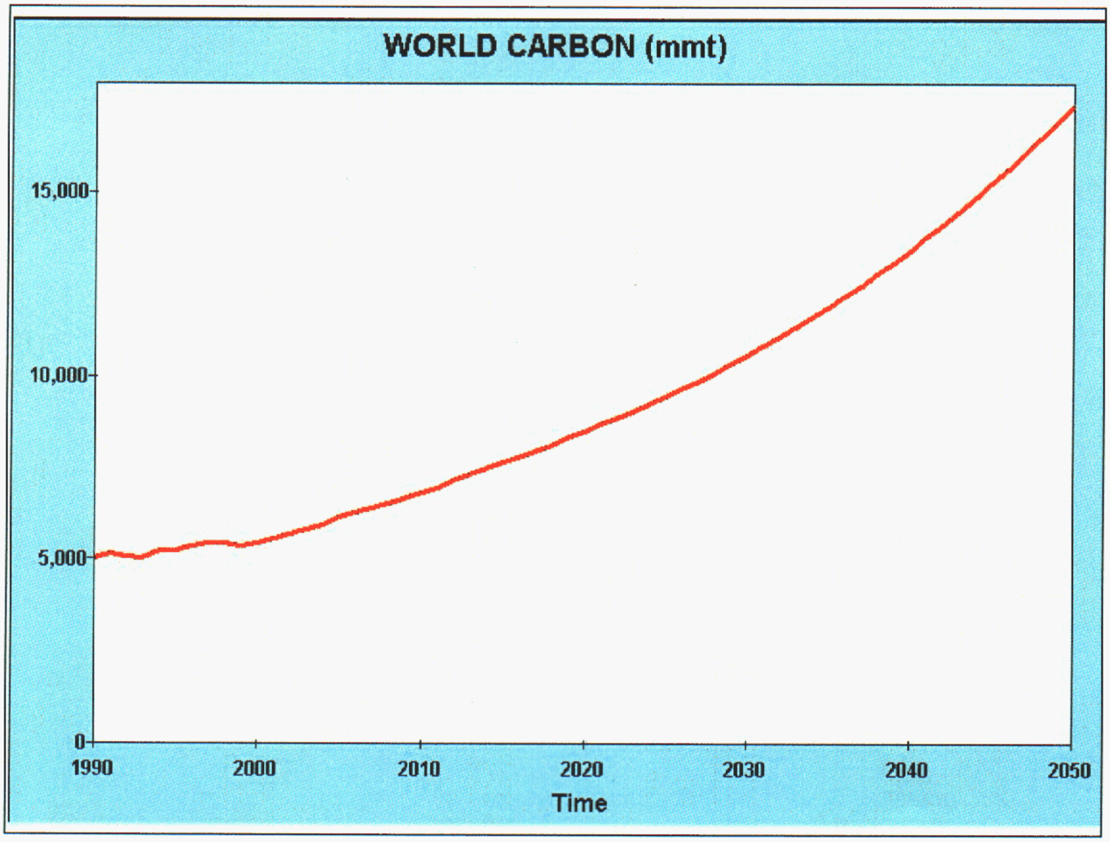

Figure 5. Historical and Extrapolated Annual World Carbon Emissions (Million Metric Tons).

Figure 6 lists the forms of plutonium considered to be the most appealing to a potential proliferator with weapons (red), pits (green), surplus weapons-grade plutonium (dark-blue), first commercial reprocessing (brown), second commercial reprocessing (purple), and spent fuel (light blue). They are ranked from the one with the most appeal to a proliferator (No. 1) to the least appealing (No. 6).

The dominant form, in terms of quantity, is plutonium in spent commercial fuel, at the bottom of the proliferability scale. Spent fuel is considered to be inherently safe in terms of proliferation because it is so difficult to handle safely. The second most dominant form, also in terms of quantity, is plutonium from the first commercial reprocessing of spent fuel. This corresponds to nuclear fuel burned a single time in a nuclear reactor and then separated into uranium, plutonium, and fission products. Separated plutonium is well below weapons-grade in isotopic purity, but a proliferator could use it, with some difficulty, to build a weapon.

Figures 3 through 6 demonstrate a few of the many results produced by the GEFM. Additional output values can be accessed through the “World Results” and “Regional Results” buttons on the main menu.

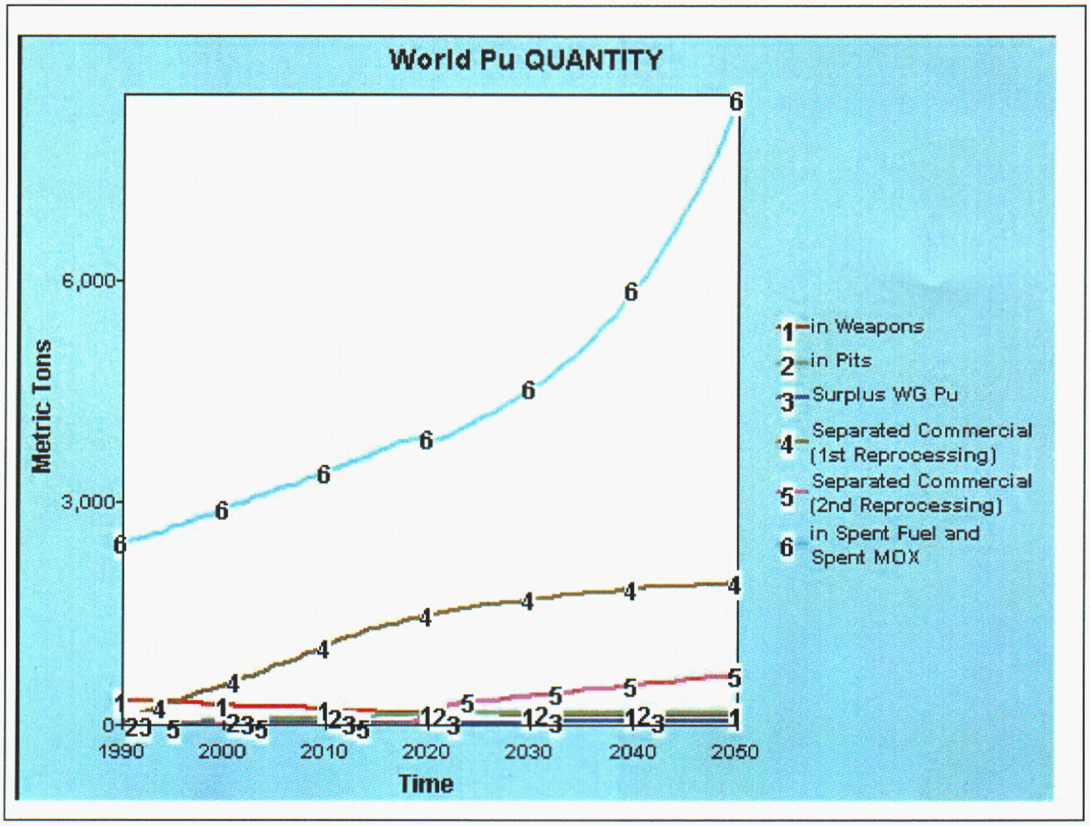

Figure 6. Accumulated Quantities (Metric Tons) of Plutonium.

H. Conclusions

The GEFM has been created to facilitate high-level exploration of energy, environmental, economic and nuclear energy options. It offers a user-friendly, integrated framework to investigate a range of consequences associated with energy decisions and policies. The model is segmented into five major regions of the world so that regional consequences, as well as integrated global consequences, can be considered. The model contains six modules that, together, account for the flow of nuclear materials within and between the commercial energy and defense sectors. The consequences considered range from environmental impacts to potential nuclear material availability within each of the five regions. The hope is that the GEFM will help facilitate national energy, environmental, economic and national security policy debate.

This work, performed under the support of Laboratory Directed Research and Development funding, was conducted at SNL, a multi-program laboratory operated by Sandia Corp., a Lockheed-Martin Co., for the DOE under contract DE-AC04-94AL85000.

2. Energy and Greenhouse Gas Emissions Module

A. Overview

The purpose of the Energy and Greenhouse Gas Emissions module is to provide a fuel-based estimation of energy use with an emphasis on nuclear power and electricity generation, Figure 7. It also provides the basis for the input to the environment and proliferation modules. Fuel consumption is modeled over time in oil, coal, natural gas, nuclear, and renewable fuel types. Special treatment is given to the electricity sector for each of these fuels with additional detail included for electricity produced by nuclear power plants. This module calculates detailed fuel cycle requirements and wastes for the nuclear fuel cycle using gigawatt hours of electricity [GWh(e)] as input. Carbon emissions from burning are calculated for all fuel types. The model is driven by fuel consumption that is derived from GDP. No consideration is given to supply limitation or price.

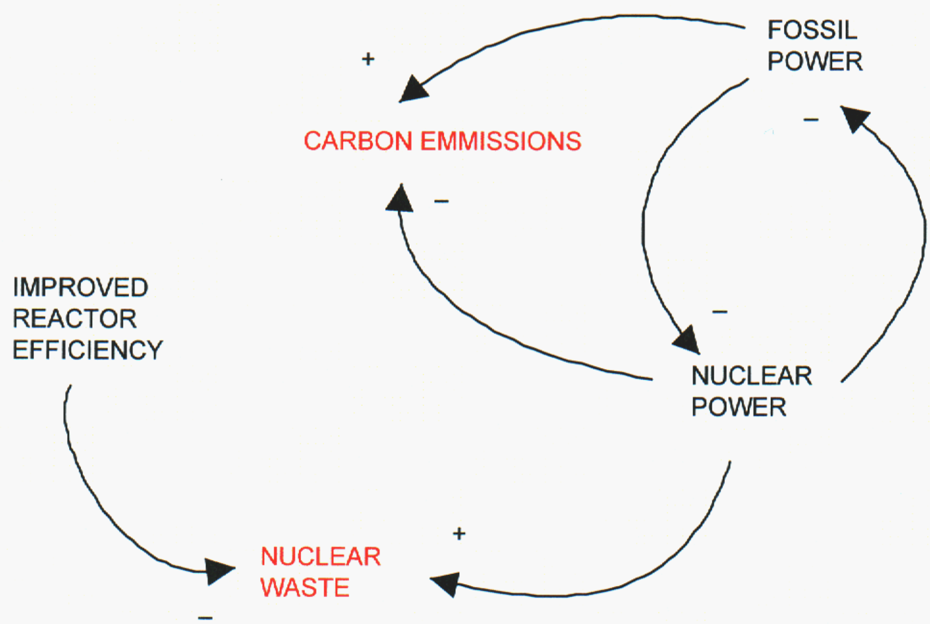

Figure 7. Causal Loop Diagram for Nuclear Power.

B. Major Assumptions

This module uses the DOE's International Energy Outlook (IEO) 2001 energy-consumption totals and fuel distributions. It is driven by IEO estimates to 2020 and then the estimate is extrapolated to 2050 using a linear trend from 2015 to 2020 using DOE's GDP figures and the relative shares of fuel types per sector. Nuclear reactors and their electricity production are calculated from the International Atomic Energy Agency (IAEA) Microcomputer Power Reactor Information System (MicroPRIS) 1999 data set. We assumed throughout the life of the simulation that the reactor-type relative percents [e.g., the LWR, RBMK, Canadian design (CANDU), and gas cooled] remain at a fixed percentage in terms of gigawatt hours of electricity (Gwe) produced in 1999.

No prices or limitations on fuel supplies were considered. Oil, natural gas, coal, and oil consumption add to global carbon emissions. Nuclear and renewable energy consumption yields no carbon emissions. The World Information Service on Energy (WISE) uranium calculator was used to calculate fuel cycle front-end requirements and wastes.

C. Module Description

This module is the driver for the fuel cycle back-end and environment modules in the model. One of its key drivers is GWh(e) [Gigawatt hours of electricity] consumed in the world categorized by fuel type. The proportion of energy consumed by fuel type can be altered in the model. Additionally, the proportion of fuel type used in the electricity, transportation, and rest-of-economy sectors also may be modified. The nuclear fuel cycle that produces electricity is fully developed to estimate mining, milling, conversion, enrichment, and fuel fabrication amounts of material from a given GWh(e). The front-end of the fuel cycle also includes milling, mining, conversion, and fuel-fabrication wastes.

These fuel-cycle inputs and outputs can be altered by changing the 1) proportions of the five reactor types (LWR, RBMK, CANDU, gas cooled, and Gen IV) used to produce electricity, and 2) fuel use and consumption characteristics of the individual reactor types.

The GDP growth rate can be modified from the DOE EIA Reference Case. Users also can change the GDP rates and GDP rates of growth as well as the energy intensity. Energy intensity in the Industrial, Transportation and Other sectors is the total energy consumption in quadrillion BTUs divided by the GDP in each year. The measure is used due to the lack of sectoral GDP contributions per region. In the electricity sector, users can change energy-efficiency rates. Energy efficiency is defined as the BTUs of source fuel used to create a British thermal unit (BTU) of electricity. Fuel consumption figures are linked to GDP at five-year endpoints, starting in 2000. Values for years not evenly divisible by five are interpolated.

The Energy Module offers a number of options including;

- Economic growth rates by Region,
- Energy intensity for each three sectors (industry, transportation, and other) and energy efficiency for electricity, in each region, and
- Fuel shares for each sector in each region. (The fuel shares modeled are coal, natural gas, oil, nuclear, and renewables.)

The Energy Module is subdivided into the sub-modules described below. Please see their associated diagrams for a more detailed explanation.

The GDP sub-module describes a primary GEFM driver, GDP, and permits selection of a GDP scenario. It is shown in the Figure 8 GDP sub-module. The Industrial sector sub-module describes the energy consumption in that sector, including energy intensity and fuel shares. It is shown in Figure 9 Industrial sector sub-module (Note the Industrial sector sub-module serves as a description for the Transportation and Other sectors that are not explicitly diagrammed here). The WISE sub-module models the front end of the nuclear fuel cycle and waste generated from commercial reactors. It is shown in Figures 10 and 11 WISE sub-module Part 1 and WISE sub-module Part 2. The next sub-module in the Energy module is reactor contributions to electricity production shown in Figure 12. This sub-module shows the interplay between GWae and the derived demand for nuclear power. It also includes the capability to reduce uranium demand through the use of MOX fuels.

The last sub-module in the Energy Module is the electricity sub-module, described in Figure 13. The electricity sub-module uses the demand for electricity from the transportation, industrial and other sectors to drive the demand for electricity. The supply of the electricity is divided among fuel types based upon historical fuel share trends in the electricity sector.

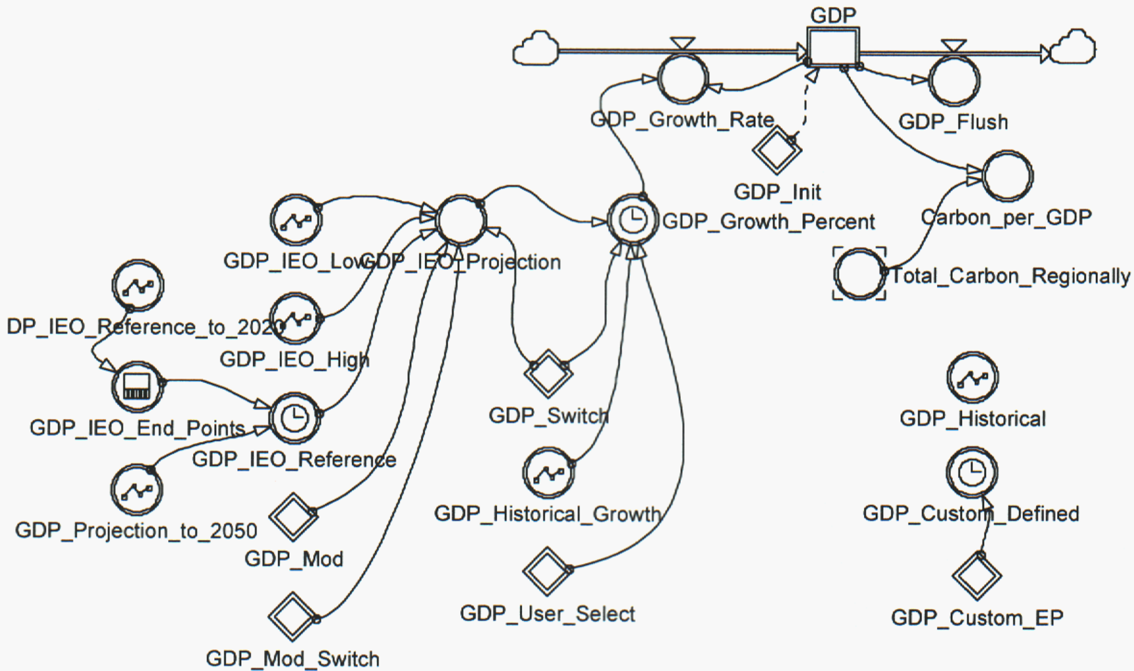

Figure 8. GDP Sub-module.

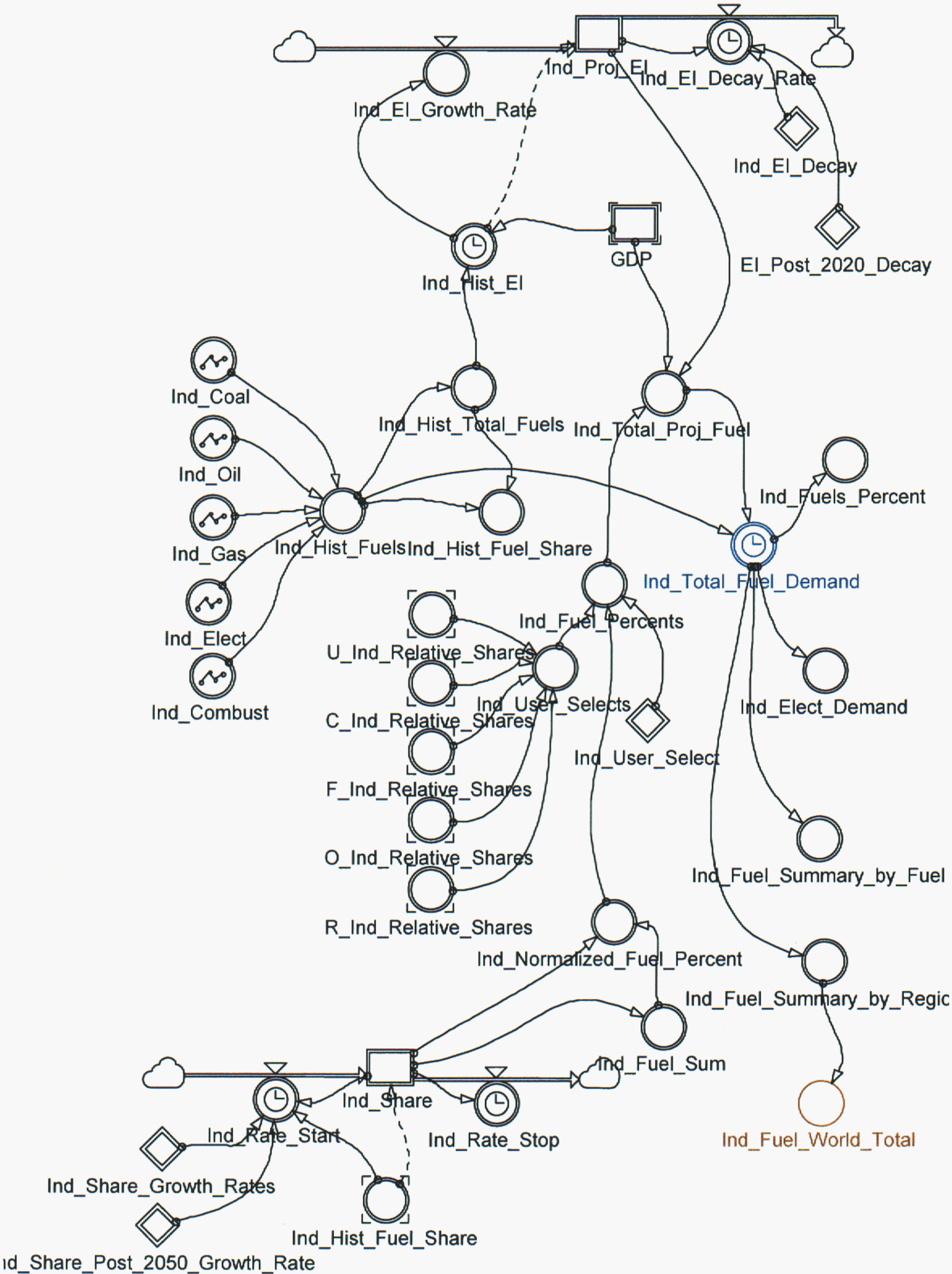

Figure 9. Industrial Sector Sub-module.

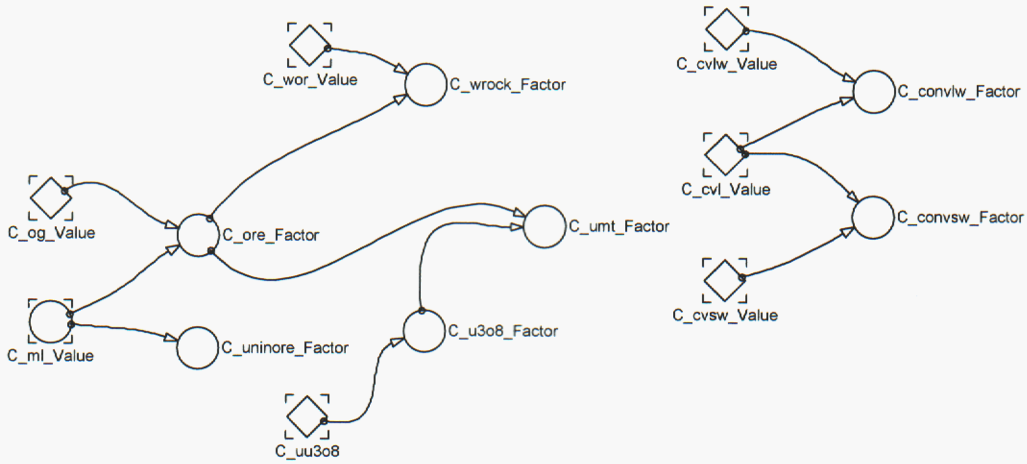

Figure 10. WISE Sub-module Part 1.

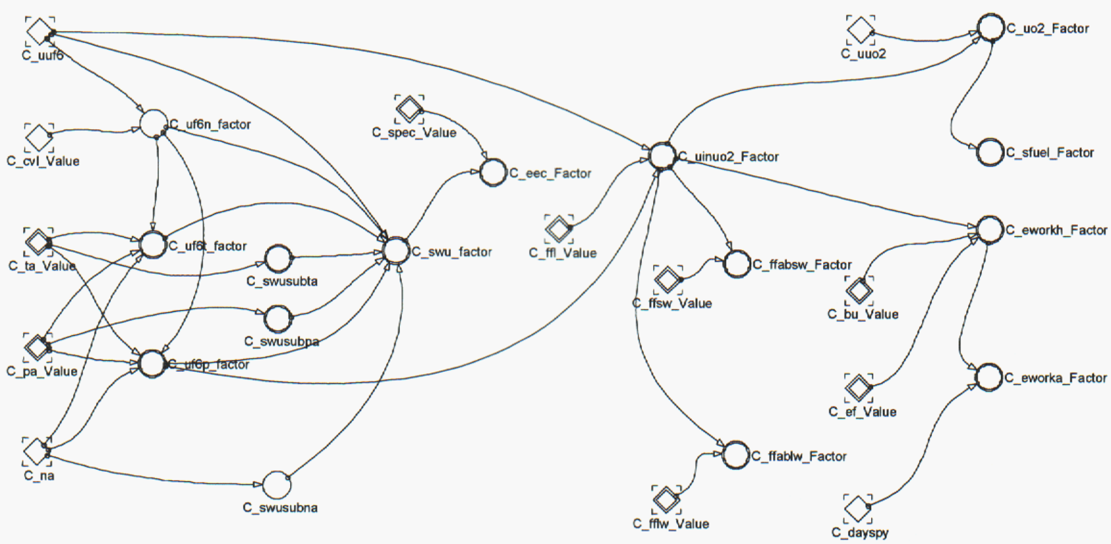

Figure 11. WISE Sub-module Part 2.

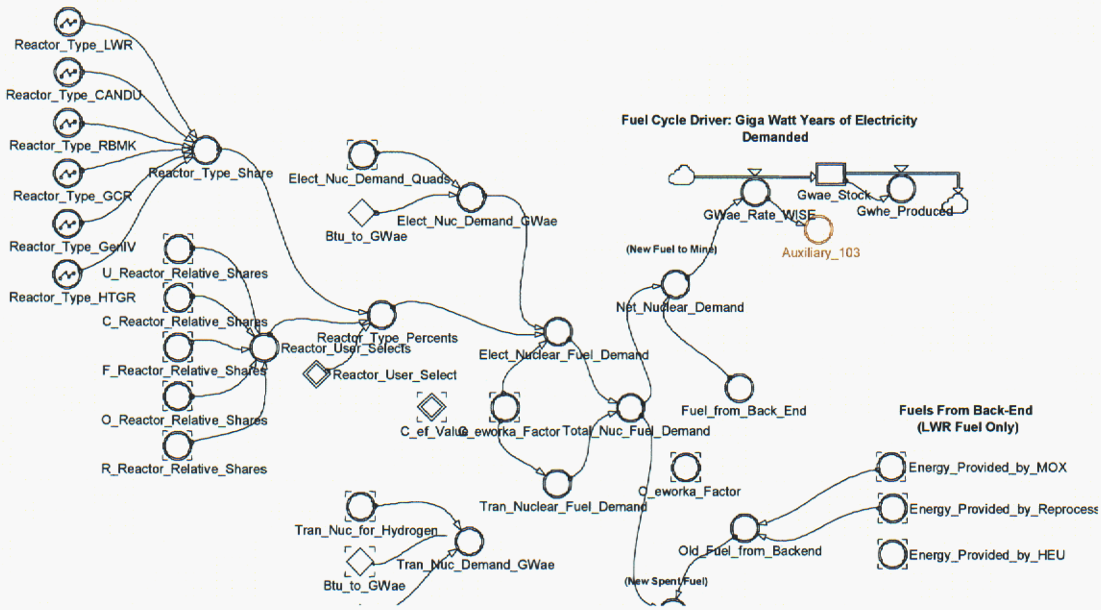

Figure 12. Reactor Contributions to Electricity Production.

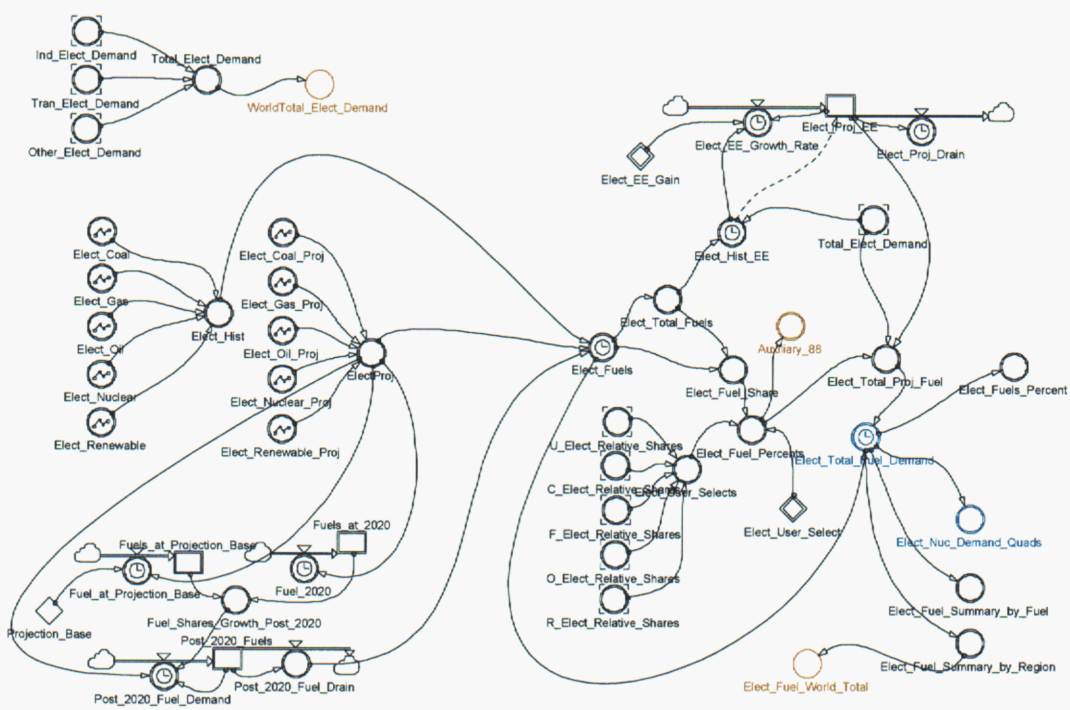

Figure 13. Electricity Sub-module.

3. Backend of the Nuclear Fuel Cycle Module

A. Overview

The Backend of the Nuclear Fuel Cycle deals with the worldwide disposition of spent fuel and surplus weapons plutonium. Spent fuel is either destined for disposal in a repository or reprocessed. Surplus weapons-grade plutonium either is made into MOX and burned in commercial reactors or vitrified. The material flows are shown below in Figure 14.

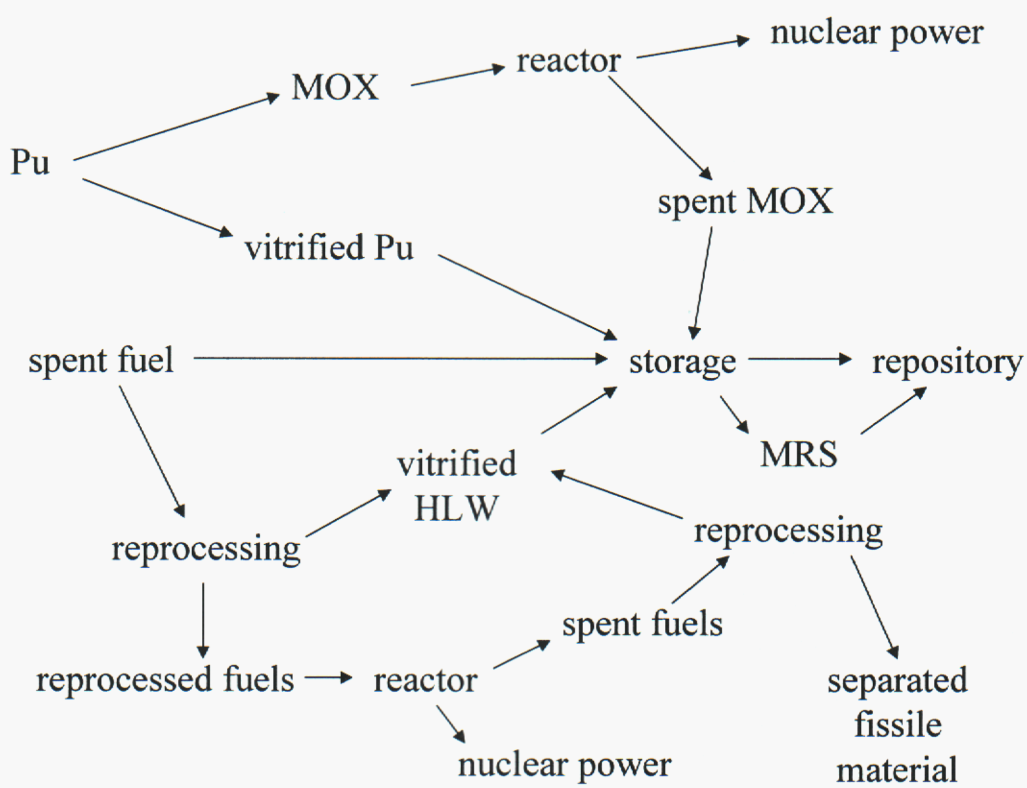

Figure 14. Backend of the Nuclear Fuel Cycle Causal Loop Diagram.

B. Major Assumptions

All spent reprocessed fuel undergoes a second reprocessing and the separated fissile material is stored, awaiting technological advances that would make this material economical to burn as fuel. When there is insufficient capacity to meet demand for reprocessing, incoming spent fuel from the energy module is reprocessed first. Any additional capacity is used to handle spent reprocessed fuel undergoing a second reprocessing. Reprocessing and MOX fabrication are based on current worldwide capacities. Users can override these defaults.

C. Module Description

This module handles the backend of commercial nuclear fuel cycle and the disposition of surplus weapons plutonium. It tracks flows of materials of interest as a function of time. The flow of backend nuclear fuel cycle materials can be altered by choosing various options dealing with: reprocessing, disposition of surplus weapons plutonium, and construction of monitored retrievable storage (MRS) and geologic repositories.

For reprocessing, users can specify the proportion of spent fuel to be reprocessed. The remainder will be destined for disposal in a geologic repository. Users also can specify the capacities to reprocess spent fuel, fabricate MOX, and vitrify high-level wastes. For disposition of surplus weapons plutonium, users can specify the proportion to be fabricated into MOX. The remainder will be vitrified and destined for disposal in a geologic repository. In addition, users can specify the capacities in the U.S. and Russia to fabricate MOX from surplus weapons plutonium and vitrify surplus weapons plutonium. Since no current capacity exists, users can specify the year these facilities will go online. For repositories, users can specify capacities for up to three repositories in each region as well as the year they will come online. Likewise, users can opt to create an MRS within each region. The following materials are destined for geologic disposal: spent fuel, vitrified high-level waste, vitrified weapons plutonium, and spent MOX derived from weapons-grade plutonium.

Model outputs are presented graphically. We show quantities of plutonium in its various forms--which has implications for proliferation. We also track the quantities of waste destined for geologic disposal. The amount of waste disposal is limited by available capacity in the repositories. Until repositories are licensed to accept waste, this waste accumulates in storage.

The backend module is connected to the other modules in the model. Spent fuel comes into the backend from the energy and greenhouse gas module. Energy produced from burning reprocessed fuels and MOX derived from weapons plutonium goes into the energy and greenhouse gas module. Surplus weapons plutonium comes in from the nuclear weapons module. Quantities of plutonium in its various forms go into the proliferation module.

Each of the sub-modules describes a portion of the Back-End Module. Although the boundary between sub-modules is not entirely clear, the module has been divided into:

- Burning Commercial MOX, Figure 15
- Miscellaneous Back-end Calculations, Figure 16
- Back-end Parameters, Figure 17
- Burning Reprocessed Uranium, Figure 18
- First Reprocessing, Figure 19
- MRS and Repositories, Figure 20
- Spent Fuel, Figure 21
- Vitrification, Figure 22
- Disposition of Weapons Grade (WG) Plutonium, Figure 23

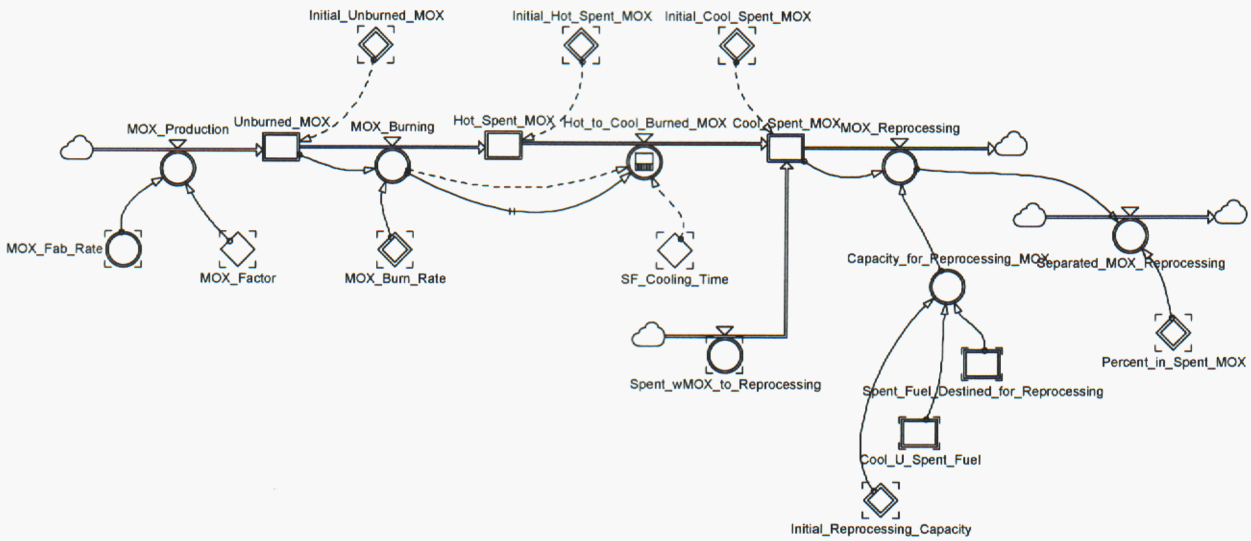

Figure 15. Burning Commercial MOX.

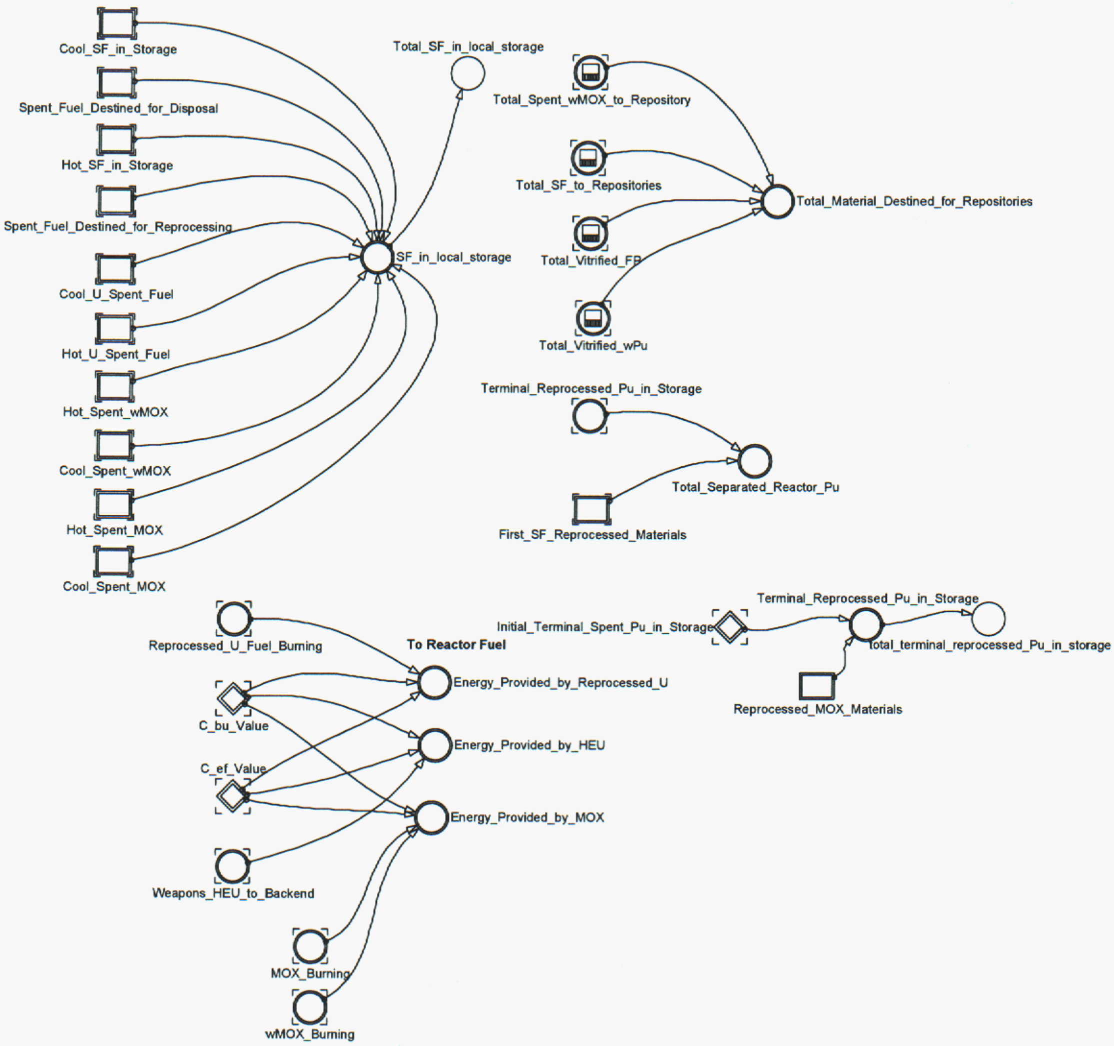

Figure 16. Miscellaneous Back-end Calculations.

Figure 17. Back-end Parameters.

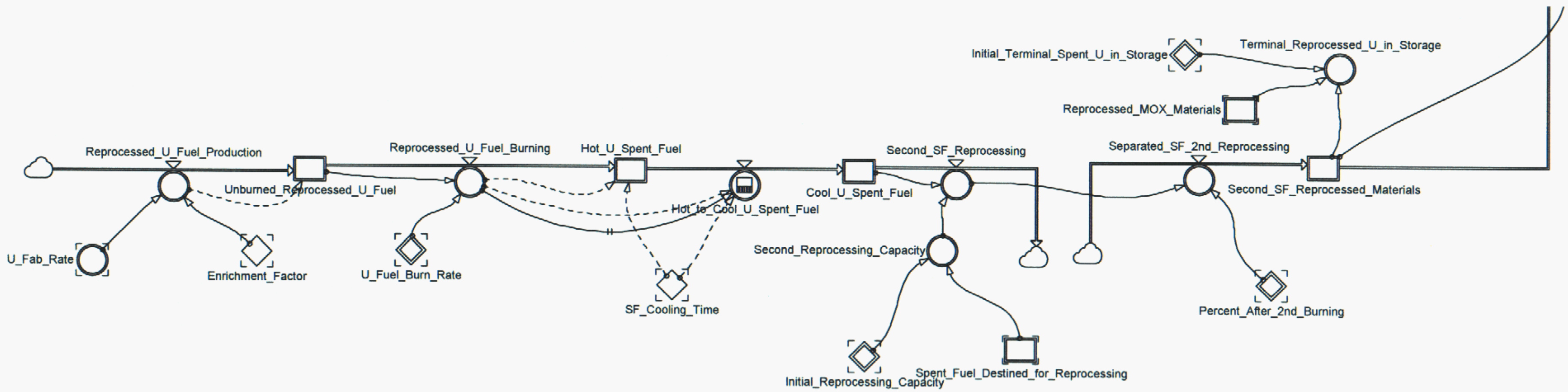

Figure 18. Burning Reprocessed Uranium.

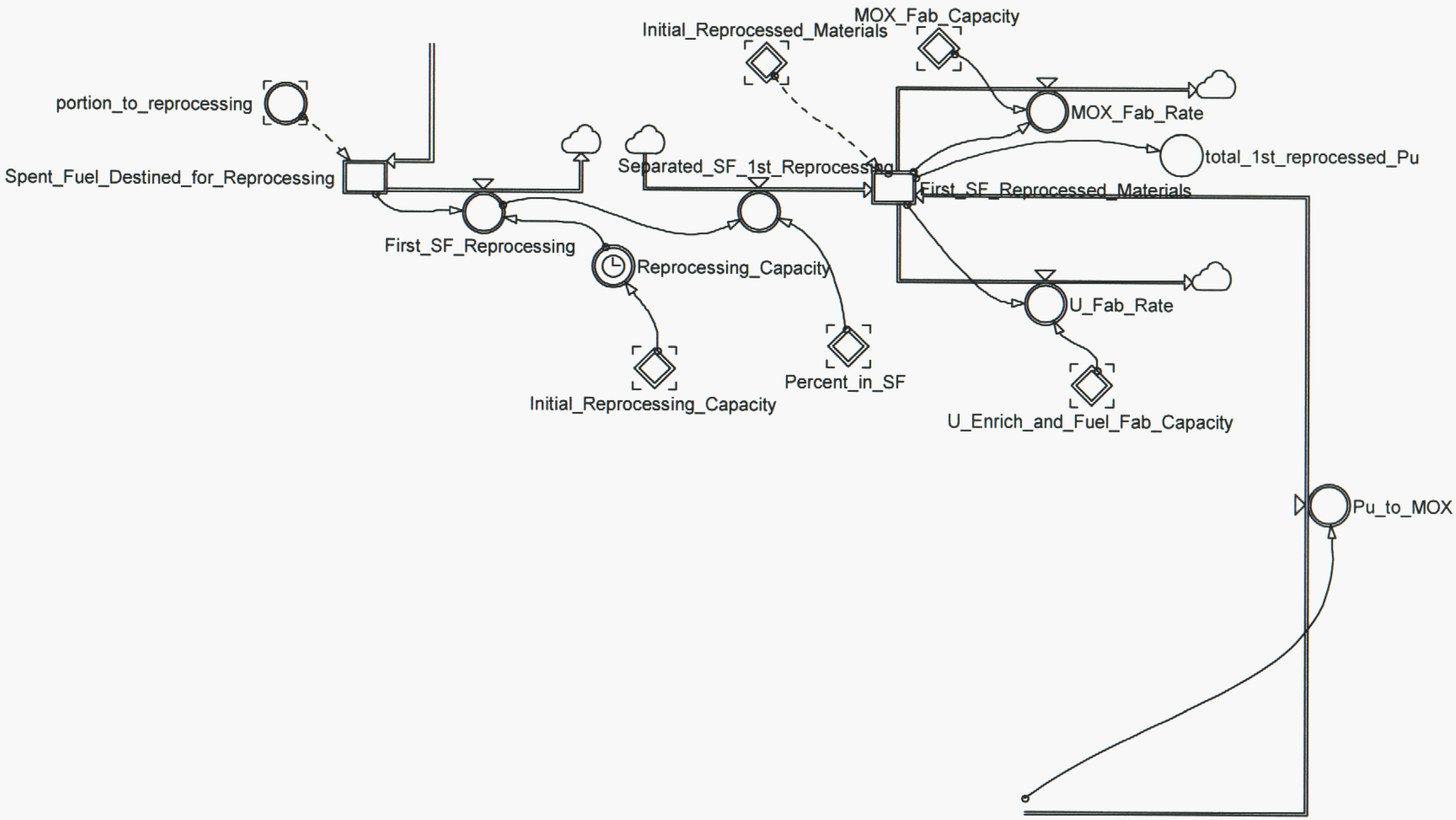

Figure 19. First Reprocessing.

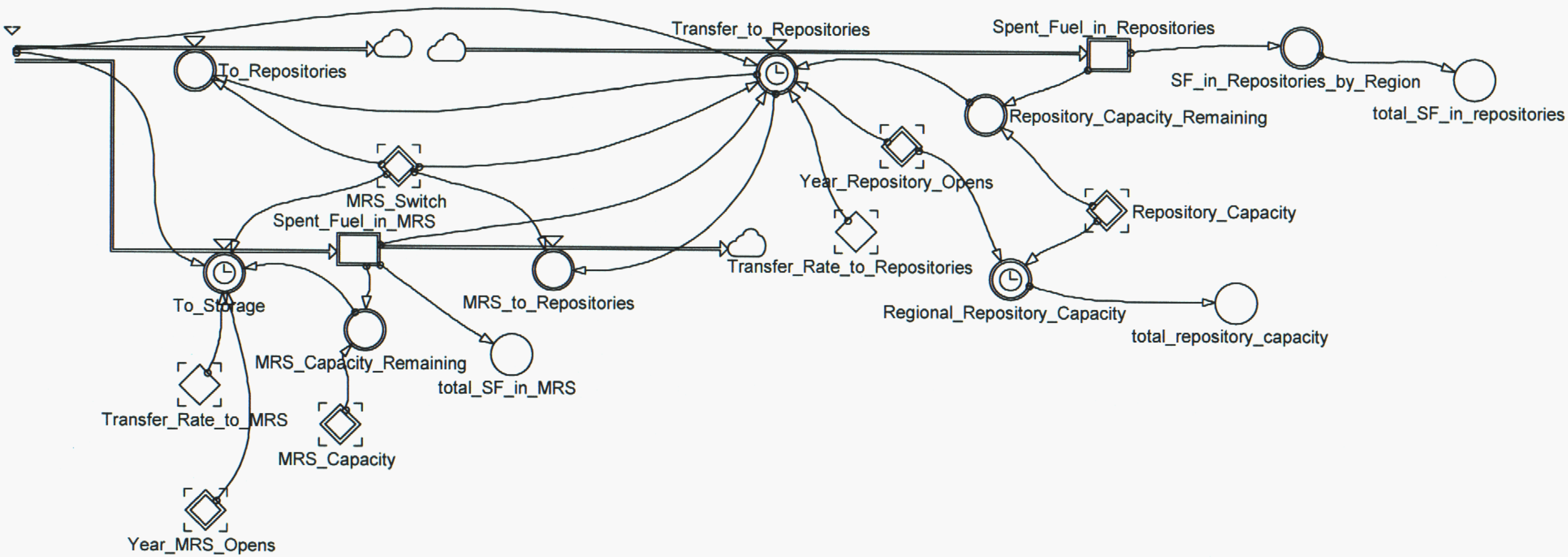

Figure 20. MRS and Repositories.

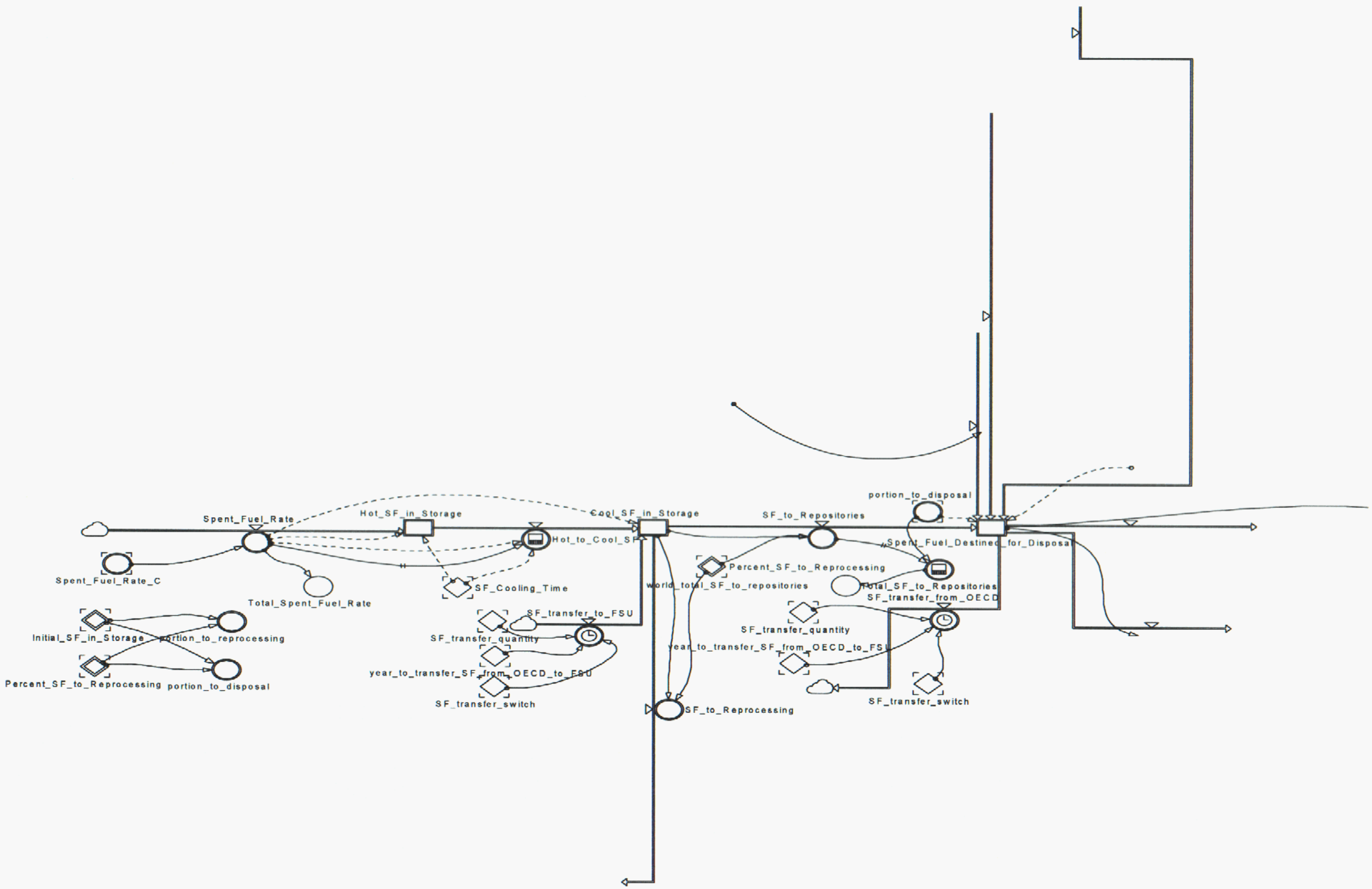

Figure 21. Spent Fuel.

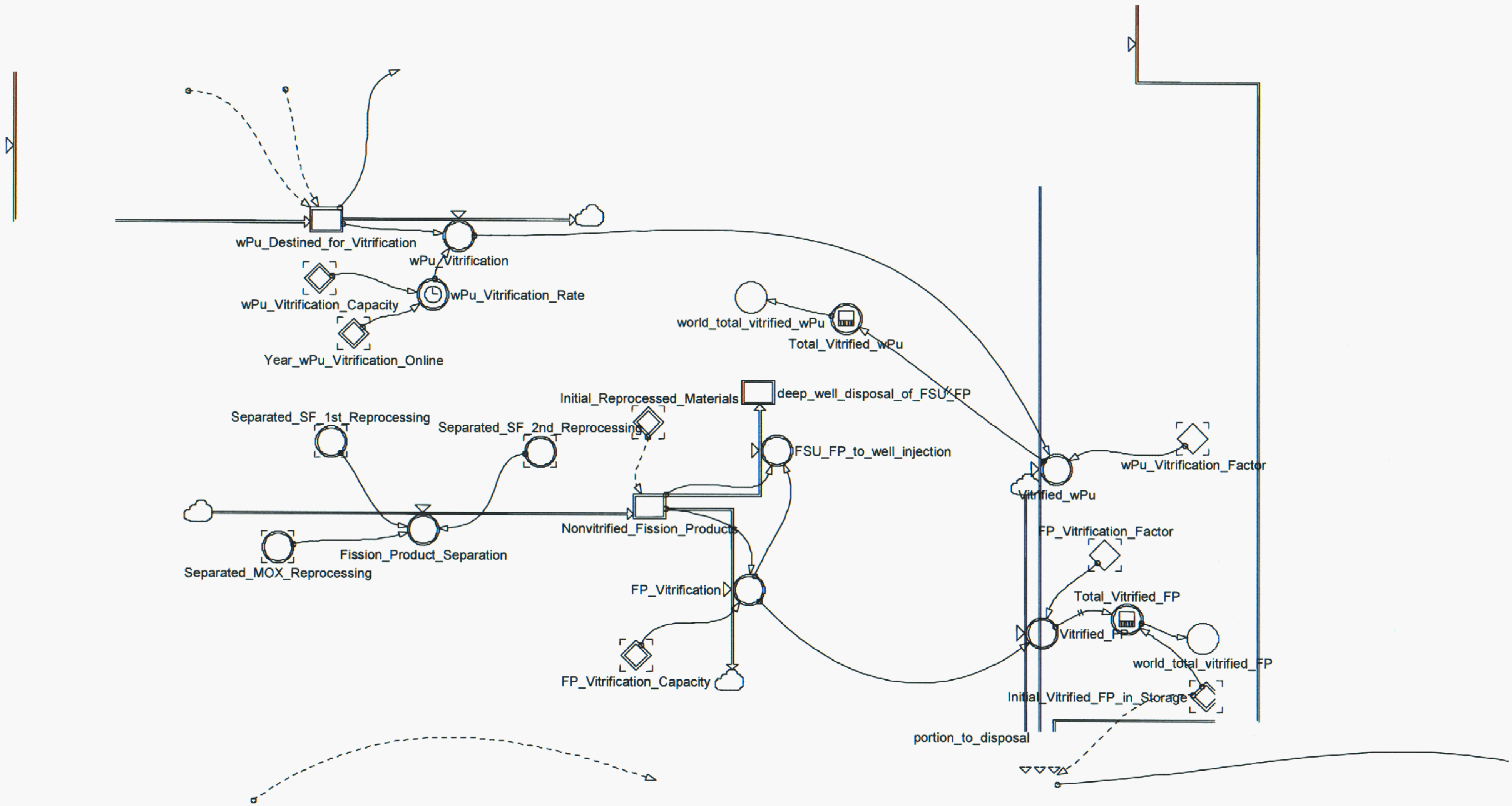

Figure 22. Vitrification.

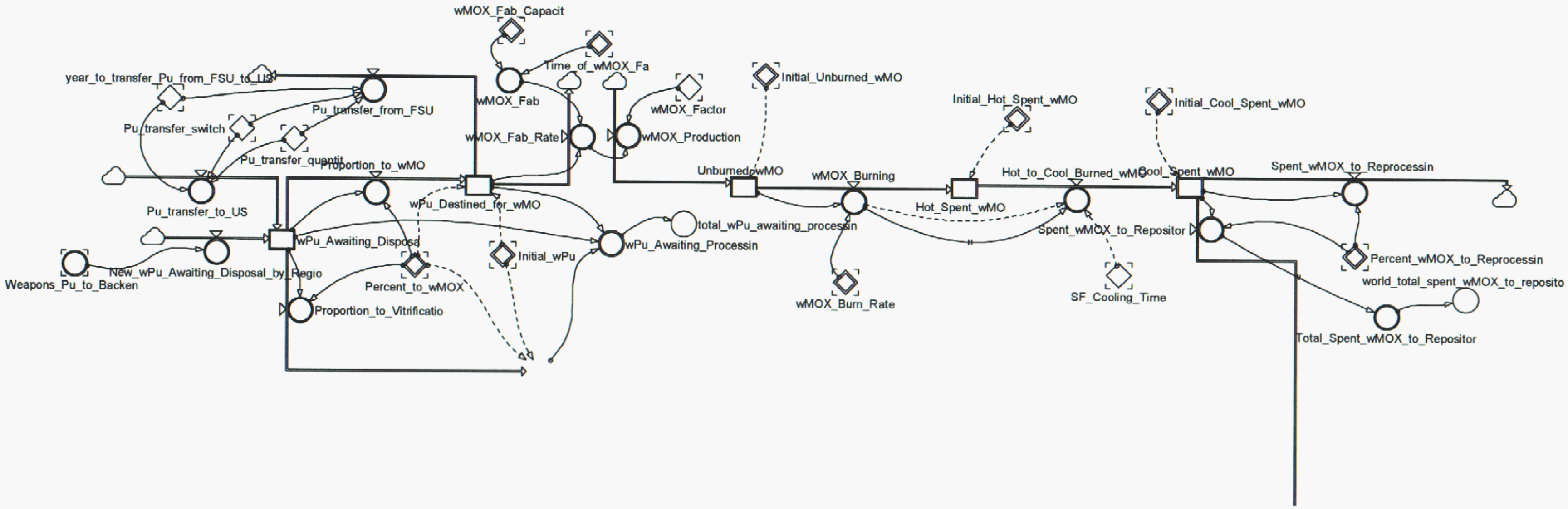

Figure 23. Disposition of Weapons Grade (WG) Plutonium.

4. Defense Nuclear Materials Module

A. Overview

The defense nuclear materials module of the Global Energy Futures Model tracks the weapons, pits (fission primary less explosive) and HEU components, and unassociated HEU and plutonium (Pu) held within the weapons programs of nuclear-weapon nations throughout the world. The purpose is to provide feedstock to the nuclear-fuel cycle when weapons materials are disposed of via the civilian nuclear power complex. The GEFM model is designed to provide historical values for all variables from 1990 to 2000. Because actual numbers of U.S. weapons are classified, historic values from 1990-2000 are representative only. Unclassified data on the numbers of pits and dismantlements is available for the years before 1996. Representative data is used thereafter. Values for the other regions are taken from open source references. There cannot be an actual balance between the publicly released mass of fissile material and numbers of weapons, pits, and HEU components because the masses of Pu and HEU used in weapons is classified. Users are encouraged to replace the representative values with their own estimates.

The weapons processes modeled here are as follows:

- Pit production;
- HEU component production;
- Weapon production;
- Residence in the active stockpile, the reserve stockpile, and retired status;
- Dismantlement; and
- Disposition of fissile materials.

Because future stockpile levels are highly uncertain and almost entirely determined by governmental policies that cannot be predicted, users must specify stockpile levels. A frame work is included for setting weapon numbers according to stipulations of arms control agreements. Since none of the weapon nations other than the U.S. and Russia is bound by the existing nuclear arms control treaties (START I, II, etc.) and those treaties do not limit U.S. and Russian tactical nuclear weapons, future stockpile levels are difficult or impossible to determine a priori. Thus, the treaty module has not been activated. Retirement and disassembly rates govern the flow of weapons out of the stockpile.

B. Major Assumptions

Estimated or representative initial values for all historic parameters (i.e., numbers of devices, material quantities, and retirement and disassembly rates) have been provided for the period 1990-2000. Actual values generally are classified or otherwise unavailable, but the estimates provided are adequate for trend analysis. If users have better estimates or want to determine the effects of varying the parameters, the model is flexible enough to allow that input.

C. Module Description

The module follows weapons complex materials in the five model regions, as stated earlier. The U.S. and China are nuclear nations as well as regions. The FSU region incorporates Russian weapons. The OECD combines stockpiles of the United Kingdom and France. Weapons in Israel, Pakistan, and India are combined for the ROW.

The following weapons and materials are analyzed:

- Nuclear weapons in the active stockpiles,
- Nuclear weapons in reserve (includes active and inactive reserves and spares),
- Retired weapons,
- Pits,
- Unassociated WGPu, and
- Unassociated WG uranium.

The tracking begins with the capacity within each region to produce weapons. Users may determine these values. Default values are estimated for all regions. The default value for the U.S. is zero, because we have no capacity to produce pits. A pit production capacity is expected sometime in the future, so users can specify the capacity and the year that it comes online. Default values for other regions are simply reasonable estimates.

Precise current knowledge of these stockpile levels in all categories and in each tracked country are impossible to obtain due to security classifications regarding that information. Representative estimates can be made using publicly released information, but it should be noted that consistent accounting of materials and component numbers cannot be done with unclassified databases.

The sub-modules for the Defense Nuclear Materials module are as follows:

- Weapon policy, Figure 24,
- Weapon reserves, Figure 25
- Weapon dismantlements, Figure 26
- Plutonium disposition, Figure 27
- HEU part production, Figure 28
- Pit and HEU part disposition, Figure 29
- Weapon production capacity, Figure 30
- Weapon and materials totals, Figure 31
- Weapon life cycle, Figure 32

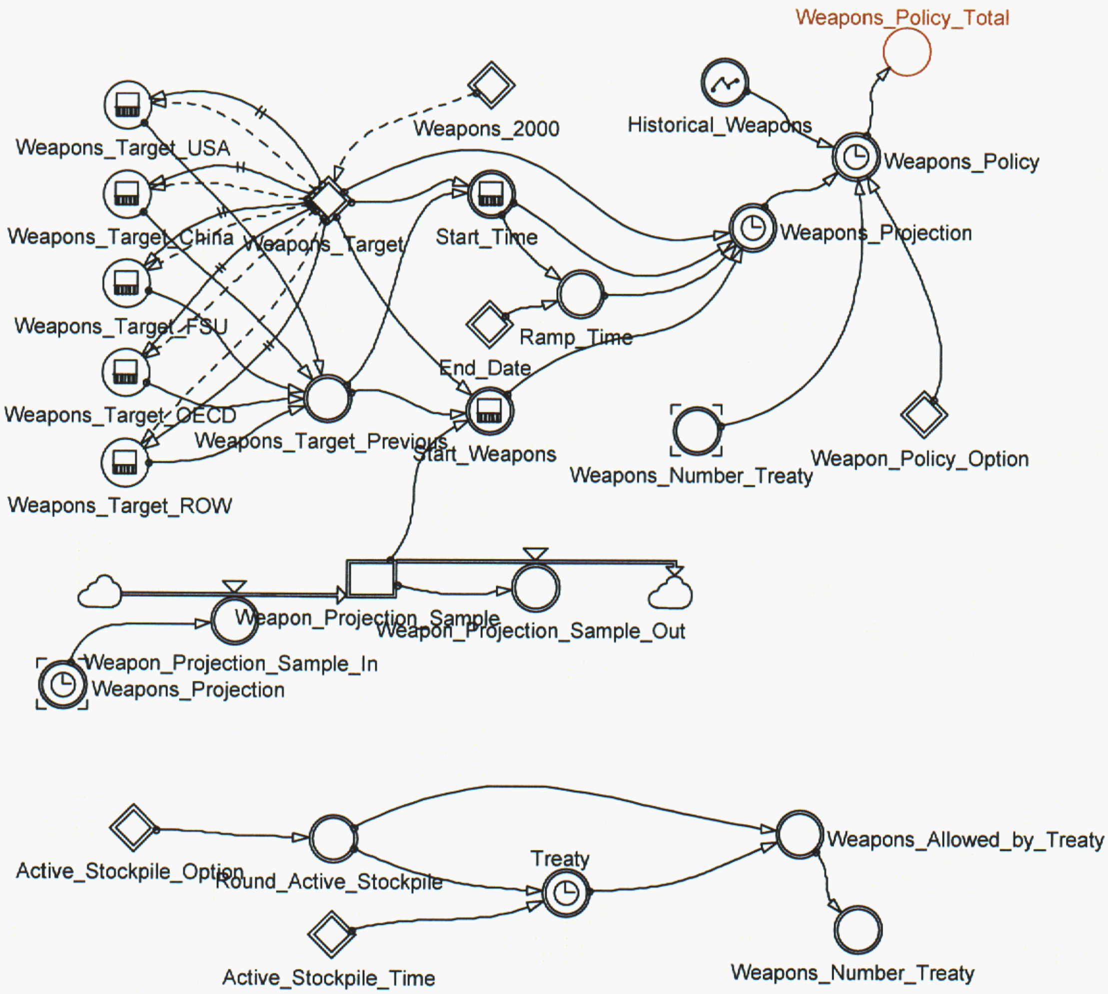

Figure 24. Weapon Policy.

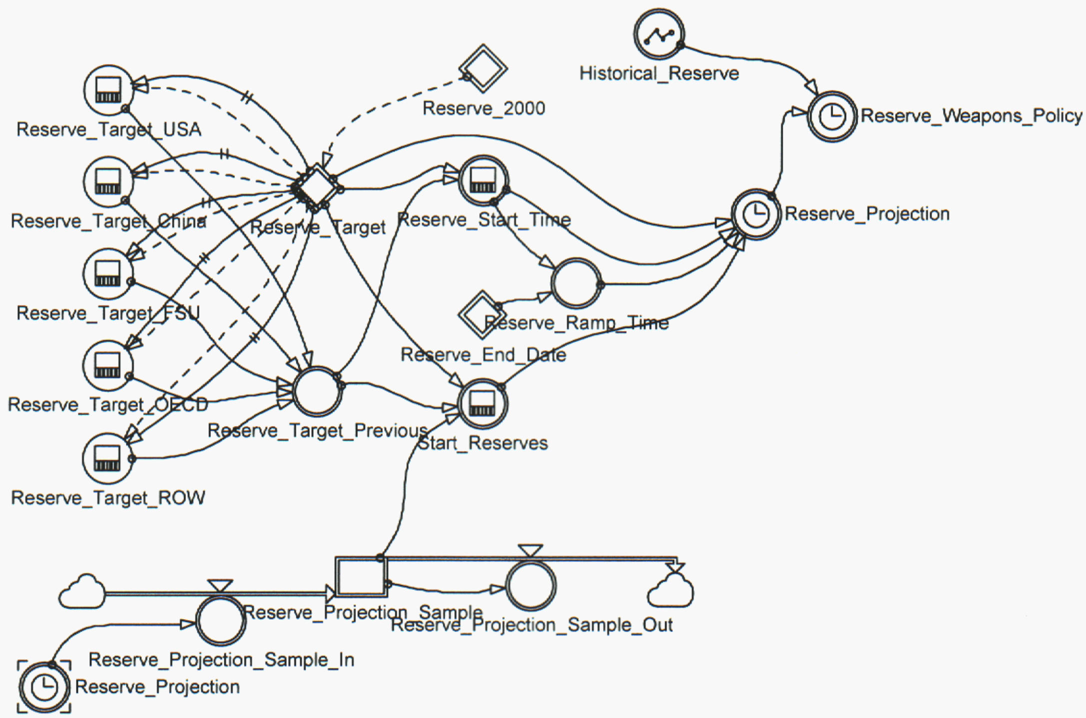

Figure 25. Weapon Reserves.

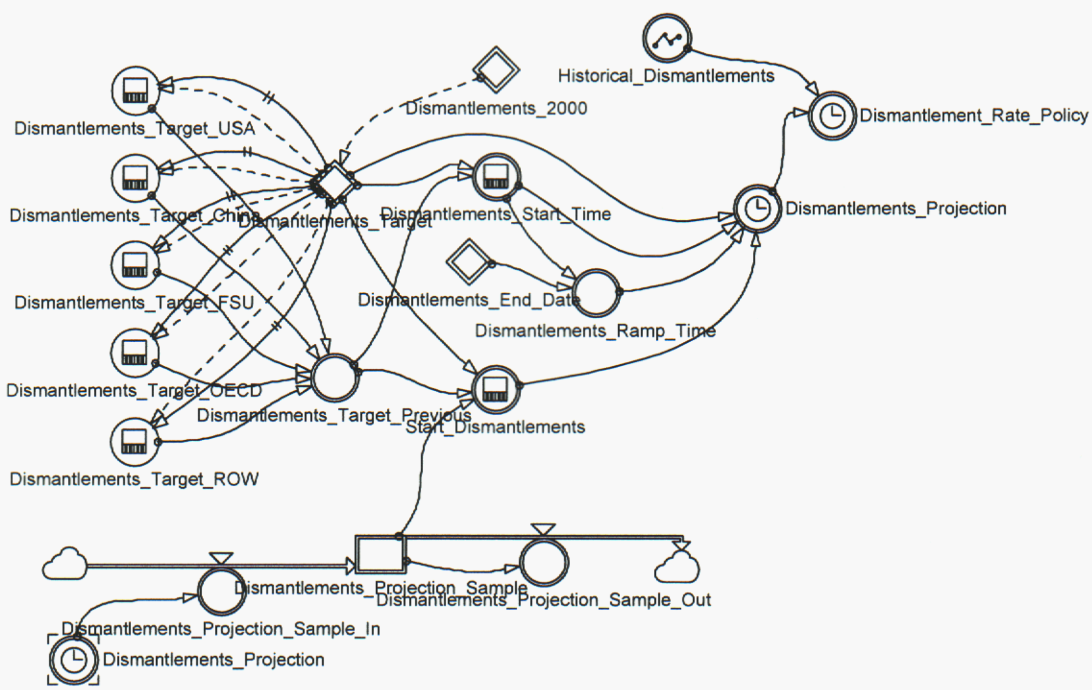

Figure 26. Weapon Dismantlements.

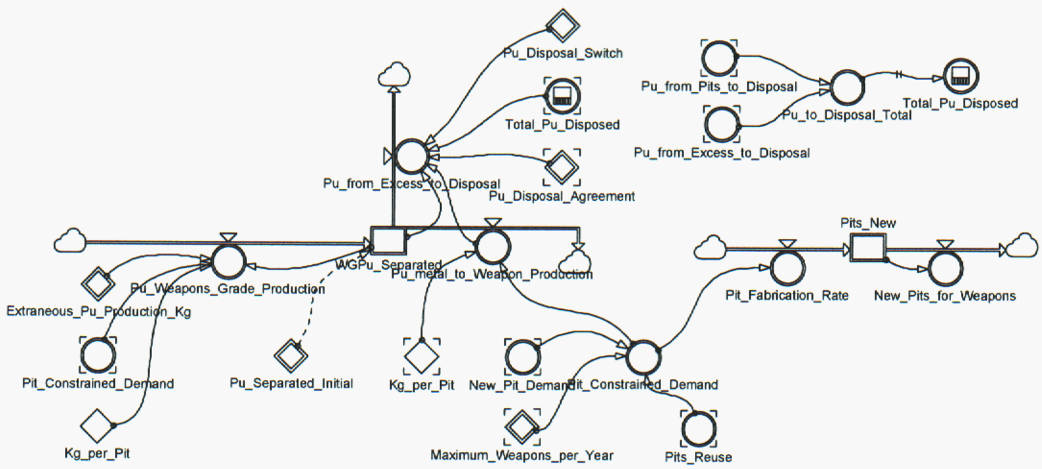

Figure 27. Plutonium Disposition.

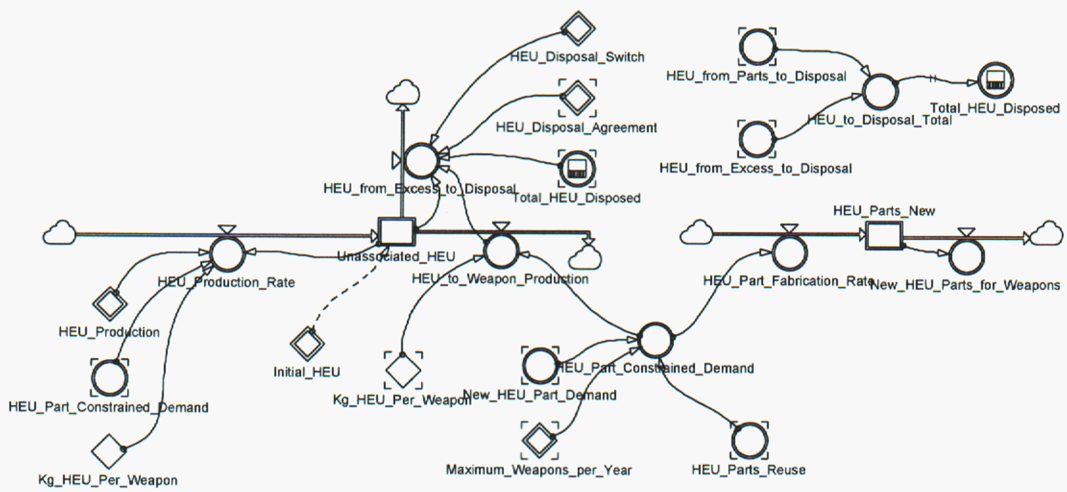

Figure 28. HEU Part Production.

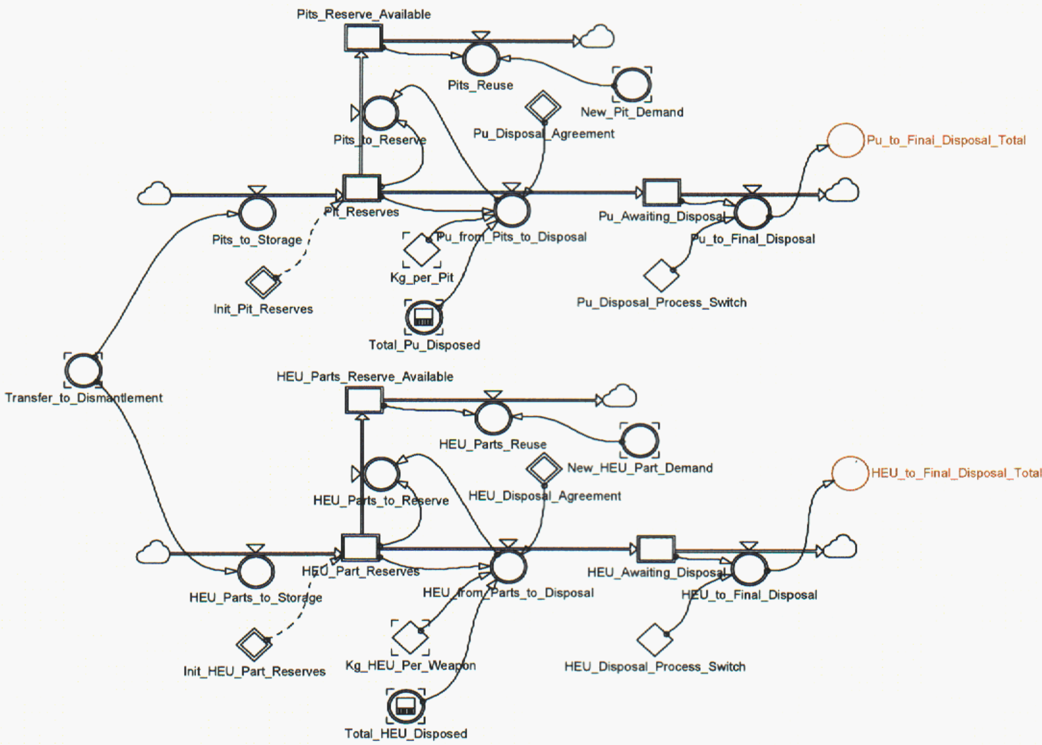

Figure 29. Pit and HEU Part Disposition.

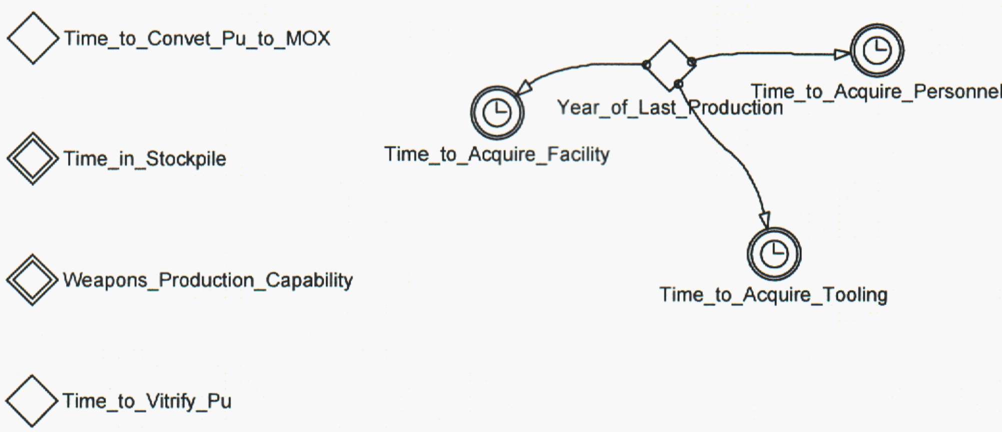

Figure 30. Weapon Production Capacity.

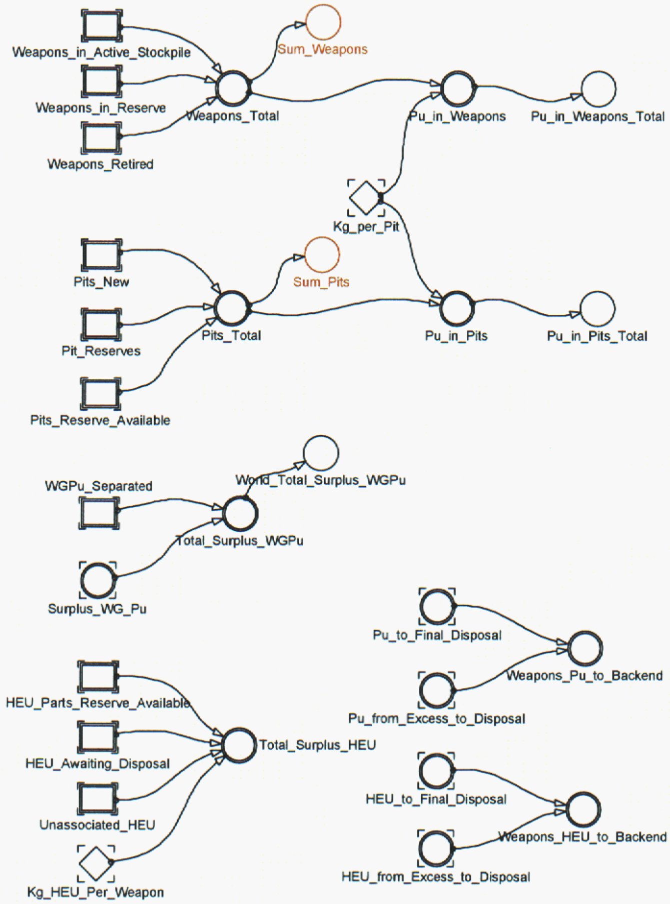

Figure 31. Weapon and Materials Totals.

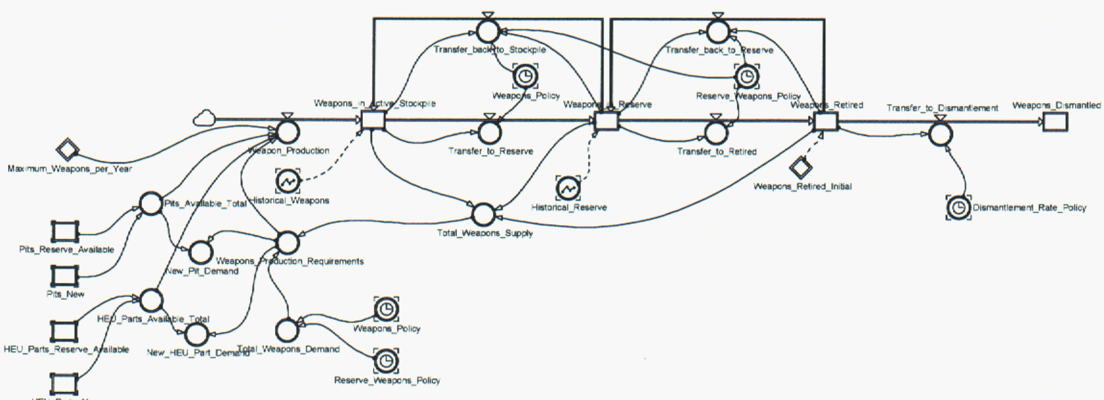

Figure 32. Weapon Life Cycle.

5. Environmental Module

A. Overview

The GEFM tracks the material flows of key materials related energy use. Major components model the redistribution and interaction of materials under the control of systems designed to produce energy or process nuclear materials needed for energy use. The purpose of the Environmental Module (EM) is to track the important effects of these systems and their associated material flows on the environment.

An ideal environmental module would track the direct and indirect consequences of all processes represented in the process models, aggregate these consequences into a few general measures (such as overall risk and cost), and include the uncertainty in these measures that results from uncertainty about the models and parameters that underlie the estimates. Such a comprehensive characterization is not compatible with the scope and objectives of the GEFM. First, estimating important intermediate quantities (such as contaminant concentrations in drinking water) would require much more spatial detail than a global systems model can provide. Second, selecting appropriate summary measures (such as risk or cost) is not a clear-cut technical decision, and estimating their values introduces many new assumptions and uncertainties into the model (for example, the definition of exposure scenarios).

For these reasons, the Environmental Model characterizes environmental impacts along a number of distinct axes listed in Table 1. Each axis closely corresponds to an immediate measurable consequence of some step in the process of energy production or use. For example, one axis measures the mass of methane (a greenhouse gas) discharged into the atmosphere. Another measures water consumption. Calculated values for each measure include contributions from diverse fuel sources, and various phases in the production and use of the fuel. Users can examine consequences of alternative policies or scenarios on each of these separate measures. This model does not combine the measures into a single indication of environmental "goodness"–users must make their own judgments about the relative importance of methane emissions and water consumption, for example.

Table 1. Environmental Measures Used in the Nuclear Enterprise Model

Impact	Units
Carbon dioxide discharge rate	MMTCE per Year
Methane discharge rate	MMTCE per Year
Discharge rate of particulates	MMT per Year
NO_x discharge rate	MMT per Year
SO_2 discharge rate	MMT per Year
VOC discharge rate	MMT per Year
Mercury discharge rate	MT per Year
Radioactivity discharge rate	Ci per Year
Discharge rate of Ash/Sludge	MT per Year
Water consumed	BCM per Year

Impact	Units
Water impacted	BCM per Year
Land for Facilities	Km^2
Land Impacted	Km^2

Selecting the set of environmental metrics was a four-step process:

1) A number of studies evaluating environmental consequences of energy production and use were reviewed to understand the range of environmental impacts commonly considered. This survey identified 145 impacts associated with energy production and use, listed in Appendix Table A-1.1.

2) These impacts were classified according to the nature of the impact (e.g., material discharged; resource consumed, compromised, or damaged) and the stage of energy production in which they occurred. This classification was used to structure the environmental model, as described below.

3) The immediate physical alteration of the environment leading to each impact was identified. Measures of these alterations became candidates for environmental metrics calculated by the model. The intent was to define a measurable quantity to track the impact, without requiring site-specific transport and exposure modeling to estimate the impact value itself. As an example, damages caused by acid rain and soil nitrification are widely watched consequences of fossil-fuel combustion. Damage estimates must draw on many situation-specific factors (such as elevation of emissions, weather patterns, and proximity of discharge location to various receptor types) and are highly uncertain even when such information is available. Calculations of this kind are impractical within the scope and resolution of this model. Instead, the total rate of discharge of acid rain precursors was calculated. This does not provide an estimate of the amount of land or property damaged by acid rain, but it does allow scenarios to be compared on the basis of precursor production: significantly reducing the mass of precursors is likely to reduce damages due to acid rain, whatever those damages actually are.

4) Emissions factors were estimated for each of the selected metrics. These factors typically describe the amount of material discharged (or resource consumed) per unit of throughput or capacity. Many factors have a wide range of reported values in the literature, arising from differences in equipment design and condition, differences in operating conditions, variations in fuel composition, differences in applied emissions control technologies, and other causes. Rather than selecting a single value for each factor, a range of values was defined reflecting possible variations in conditions reported in the literature. Users are encouraged to explore the effect of using high, low, or intermediate values when comparing scenarios.

The resulting environmental characterization allows alternative energy-production scenarios to be evaluated along several diverse dimensions. However, there are some limitations to the model, as mentioned below.

Some types of impacts cannot be quantified in a straightforward way. (For example, the visibility and noise impacts of power plants and other infrastructure elements are determined almost entirely by their location and cannot be resolved by our global model. These impacts were not included.)

Deaths and injuries from industrial accidents were not included as an environmental metric.

The overall simulation is deterministic. Impacts with a greater certainty of occurring are easily incorporated. Allowing users to select from a range of possible emissions factors incorporates uncertainty in occurrence rates of these chronic consequences. Events with a very low probability of occurring, but a high consequence if they occur (such as a reactor core breach) are difficult to represent in a deterministic model. The current model bounds possible impacts of such events by defining emissions factors ranging from 0 (i.e., the event never occurs) to an upper limit corresponding to certain occurrence. This approach produces an extremely wide range of possible consequences, suggesting the need for a better representation of low-probability events.

Estimated values for some impacts are incomplete because projections about the contributions of all stages of energy production and energy usage could not be found. (For example, the land used for pipelines and transportation networks is not included in the calculation of land impacted.)

While the model performs import, export, and inter-region transport calculations, the inter-region exchange rates are assumed to be zero in the general model. These processes currently do not contribute to calculated impact values.

The model calculates impacts resulting from future fuel uses. Impacts arising from past uses are not considered. This focus helps distinguish consequences of alternative fuel-use decisions, which only can influence future impacts, but provides no baseline for assessing the "absolute" significance of observed differences.

B. Module Description

The module is structured around the production and use of eight kinds of fuel. Use and production generally occurs in eight stages, although some stages are not relevant for some fuels. For example, photovoltaic energy doesn't require fuel production or transport. Uses consist of electricity production and consumption in the transportation, industrial, and miscellaneous sectors. Production comprises fuel production, fuel importation, intra-region transport, and fuel export. Table 2 indicates the stages considered for each of the eight fuel types.

Table 2. Stages of Fuel Use Included in Environmental Calculations.

Fuel Type	Fuel Production	Fuel Import	Inter-region Transport	Fuel Export	Transportation Use	Industrial Use	Miscellaneous Use	Power Production
Coal	X	X	X	X	X*	X*	X*	X
Oil	X	X	X	X	X*	X*	X*	X
Natural Gas	X	X	X	X	X*	X*	X*	X
Nuclear	X	X	X	X				X
Hydroelectric								X
Wind								X
Photovoltaic								X
Biomass	X							X

*For all non-generation sectors, capacity expansion and decommissioning are assumed to be independent of the type of fuel used to service the sector. Only operational damages for each fuel type are included for the non-generation sectors: capacity expansion and decommissioning damages are assumed to be insensitive to fuel choice.

1) General Damage Calculation for Fuel-Use Stages

For each fuel and in each stage included in the damage calculation, three potential sources of environmental degradation are distinguished: construction, facility operation and decommissioning. A common model structure was used to calculate impact values for each stage of each individual fuel type. Figure 33 shows this structure for a generic production stage of a generic fuel. The primary outputs (shown in red on Fig. 33) are the accumulated damages and damage rates along each dimensions used to characterize environmental performance. There are two inputs to each cell.

The Operating_Rate specifies the rate at which this Stage of this Fuel must be operated to satisfy overall energy demand under user-defined constraints and allocations. These operating rates vary with time, ultimately determined by the GDP growth rate, energy intensities, and fuel allocation. The operating rate in each stage drives three sets of potential environmental consequences. One set of environmental consequences arises from operating existing facilities at a specified rate. Some physical infrastructure is needed to sustain the current operating rate. This infrastructure may need to be repaired or replaced over time, and new infrastructure may be needed if the operating rate increases. This new infrastructure is the potential source of environmental consequences when constructed and later decommissioned. Environmental damage from decommissioning existing equipment is not included as this damage would be incurred regardless of policy options considered in the GEFM model.

The technique making the linkage between externally specified energy demands and operating rates of individual cells is described below. The Damage_Factors are the rates at which each kind of environmental damage occurs as a result of operating, constructing, and decommissioning. These factors usually are specified at the beginning of each run, and interpolated between upper and lower limits defined as constants. The calculation of these factors is explained below.

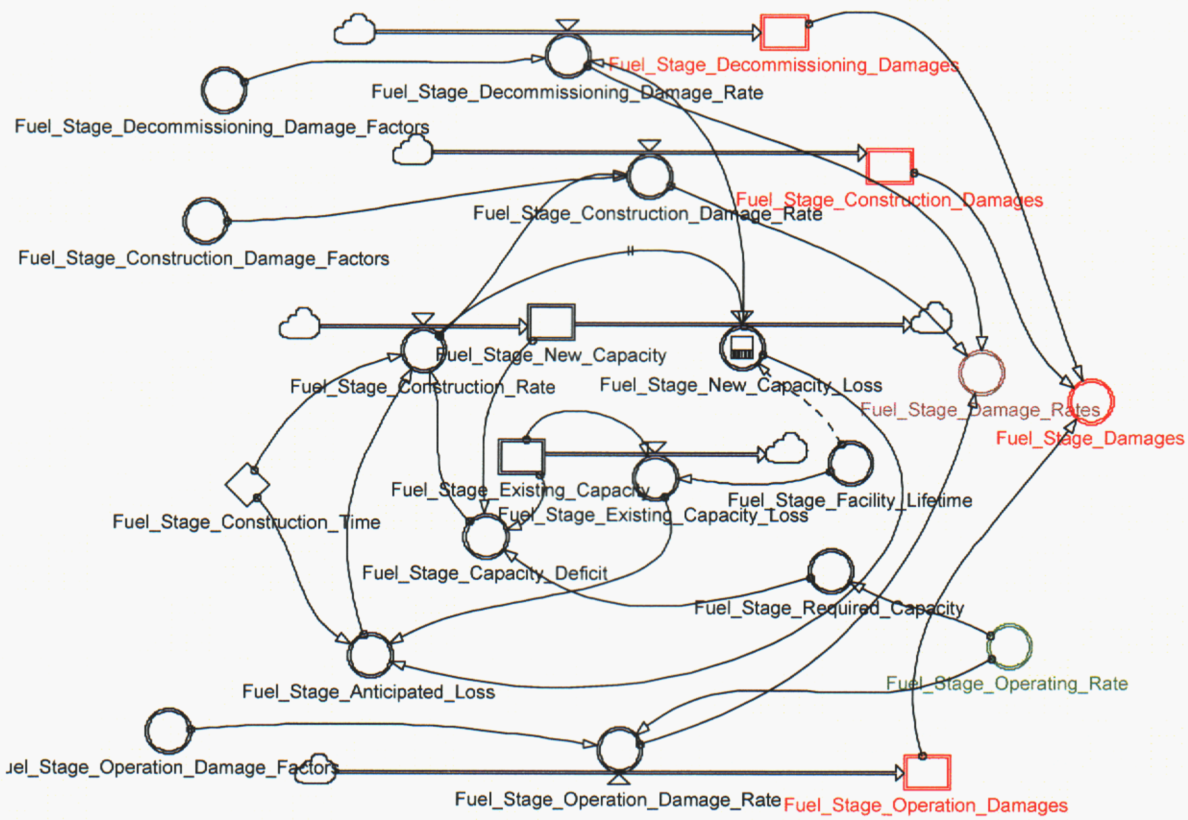

Figure 33. Flow Diagram for the Impact Calculation Cell for Each Fuel Stage.

2) Operating Rate Calculation for Each Fuel-Use Stage

The operating rates for each of the Fuel/Stage cells in the module are derived from a few feeds from the main GEFM module (that includes all other modules except for the environmental). Figure 34 shows the operating rate calculations based on the inputs from the main model. Electric_Fuels, Industrial_Fuel, Transportation_Fuel, and Miscellaneous_Fuel are each fuel's consumption rates in the power generation, industrial, transportation, and miscellaneous sectors. Because users can specify alternative scenarios for reprocessing and reactor design properties in the main model, the amount of new fuel required for nuclear power cannot be inferred in the environmental model. The U3O8_Production is calculated in the main model and used in the environmental model to calculate fuel-production damages. The allocation of production among renewable sources is defined in the main model and passed onto the environmental model, although it is not required by the main model's energy calculations. The calculations define operating rates (shown in green in Figure 34) for each of the Fuel/Stage cells used to calculate impacts.

3) Damage Factors for Each Fuel-Use Stage

Various damage factors for the Fuel/Stage cell models shown in Figure 33 are interpolated between the upper and lower endpoints, defined as constants in the model. A common interpolation factor (Relative_Impact) is used for all factors. Upper and lower limits for emission factors are listed in Appendix Table A-1.2.

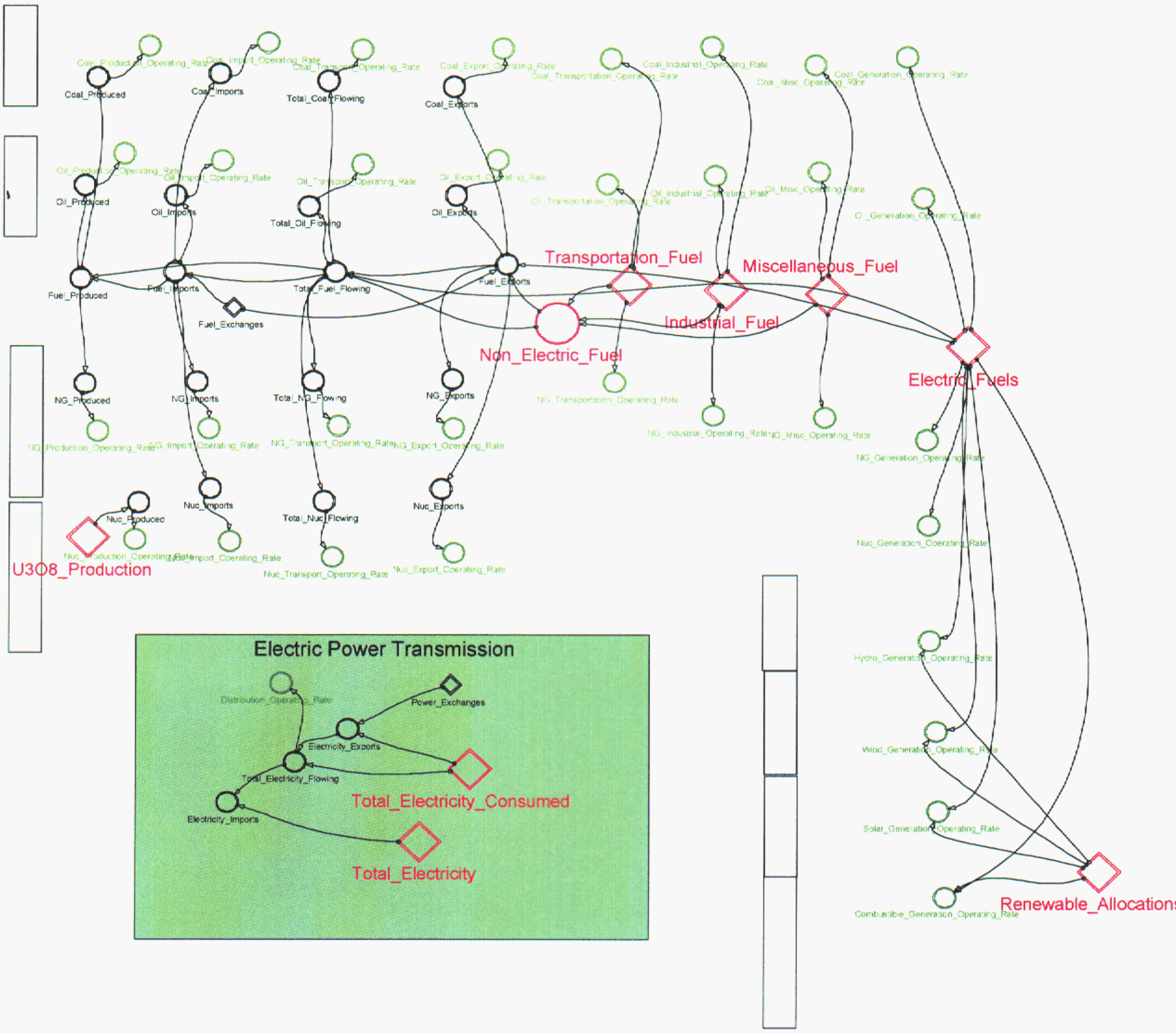

Figure 34. Derivation of Operating Rates of Each Fuel Stage from Input Rates.

6. Key Model Review Comments and Suggestions for Further Work

The Global Energy Futures Model was constructed in an iterative manner during FY2000-FY2002, beginning with a simple global model, and evolving to a more complex global and regional model. The model team partitioned the problem into the areas addressed above and continually sought out both internal and external expertise during the modeling process. During modeling, the team met approximately once each week to review individual modules and module integration.

Starting in the fall of 2001, with the initial completion of the Beta version of the complex global and regional version, the GEFM was demonstrated to and reviewed by several internal and external audiences to seek validation and suggestions for improvements. Internal reviewers included Rip Anderson, Tom Blejwas, Dennis Berry, Sue Collins, Peter Davies, Tom Drennen, Bob Eagan, Stan Fraley, Al Marshall, Jim Phelan, Gary Polansky, Dana Powers and John Taylor. External reviewers included Texas A&M faculty and staff from the Nuclear Engineering Department and George Bush School of Government and Public Service, Ernie Moniz and John Deutsch of the Massachusetts Institute of Technology, and the Sandia National Laboratories Center 5300 Distinguished External Advisory Panel. In addition to some technical suggestions that have been included, those reviewers also suggested a number of changes and improvements, including the following (Table 3).

Table 3. High Level GEFM Model Comments and Suggestions.

Emphasize this is a high level learning tool, not a forecasting tool
Develop an alternative reference case not based on the EIA IEO
Numerous cosmetic changes including: fonts, colors, and labeling
Increase allowable ranges on many of the sliders
Permit a "ramped" change in any policy variable over time
Include naval reactor fuel effects
Represent weapons as material quantities, rather than numbers
Allow material flow between regions
Consider constraints: supply, construction, laws, treaties, etc.
Dynamically choose regions to analyze
Include per capita GDP energy drivers

The modeling team will be making an effort, contingent upon funding and prioritization, to improve the model based upon these and other suggestions.

7. Summary

The Global Energy Futures Model (GEFM) is a demand-based, gross domestic product (GDP)-driven, dynamic simulation tool that provides an integrated framework to model key aspects of energy, nuclear-materials storage and disposition, environmental effluents from fossil and non fossil energy and global nuclear-materials management. Based entirely on public source data, it links oil, natural gas, coal, nuclear and renewable energy dynamically to greenhouse-gas emissions and 12 other measures of environmental impact. It includes historical data from 1990 to 2000, is benchmarked to the DOE/EIA/IEO 2001 [5] Reference Case for 2000 to 2020, and extrapolates energy demand through the year 2050.

Specifically, the GEFM contains separate modules for energy, the nuclear fuel cycle front and back end, defense nuclear materials, and environmental impacts. It is globally integrated, but also breaks out five regions of the world so that environmental impacts and nuclear material concerns can be evaluated on a regional basis for: the United States of America (USA), the Peoples Republic of China (China), the former Soviet Union (FSU), the Organization for Economic Cooperation and Development (OECD) nations excluding the USA, and the rest of the world (ROW) (essentially the developing world).

The GEFM is unique because it is a high-level, dynamic simulation tool integrating key aspects of global and regional economic growth, energy demand by sector and fuel, energy efficiency by sector, the nuclear fuel cycle (including civilian and defense nuclear materials generation and disposition) and environmental impacts. It allows the user to examine a very wide range of "what if" scenarios through 2050 and to view the potential effects across these widely dispersed, but interrelated areas.

The authors believe that this learning tool will help stimulate integrated public policy discussion on global energy, environmental, economic and national security issues by policy markers, corporate executives and their staffs. In this manner, it is hoped that this model will improve public-policy decision-making and will help guide both public and private investment in these areas, leading to improved, more cost-effective long run solutions.

8. References

Section 1

1. International Energy Agency, OECD, 2000, *Energy Balances of OECD Countries, 1997-1998,* Paris.

2. International Energy Agency, OECD, 2000, *Energy Statistics of OECD Countries, 1997-1998,* Paris.

3. International Energy Agency, OECD, 2000, Energy Balances of Non-OECD Countries, 1997-1998, Paris.

4. International Energy Agency, OECD, 2000, Energy Statistics of Non-OECD Countries, 1997-1998, Paris.

5. U.S. Department of Energy (DOE) Energy Information Administration, International Energy Outlook, 2001.

6. U.S. Department of Energy (DOE), Energy Information Administration, Annual Energy Outlook, 2001.

7. Meyer, Stephen M. "The Dynamics of Nuclear Proliferation", University of Chicago Press; ISBN: 0226521494; Reprint edition (June 1986)

Section 2

1. U.S. Department of Energy, Energy Information Administration, International Energy Outlook 2000.

2. International Atomic Energy Agency MicroPRIS (Production Reactor Information System). http://www.iaea.org/programmes/a2/

3. Worldwide Information Source on Energy, http://www.sociamedia.nl/~wise/uranium/nfcm.html.

Section 4

1. Natural Resources Defense Council Internet web site, http://www.nrdc.org/nuclear/nudb/datainx.asp

2. United States Department of Energy Memorandum, dated June 12, 1992, Subject: Citation on Colin Powell's Speech that Released National Stockpile Numbers (U) with attachments, From: A. Bryan Siebert, Director, Office of Classification, Security Affairs

3. Albright, David, Frans Berkhout, and William Walker, Plutonium and Highly Enriched Uranium,1996, Stockholm International Peace Research Institute, Oxford University Press (1997)

Section 5

1. WISE Mass-balance calculator default parameter values, http://www.antenna.nl/wise/uranium/nfcm.html

2. Uranium Institute (UI) description of the nuclear fuel cycle, http://www.uilondon.org/nfc.htm

3. Uranium Institute description of uranium ore, http://www.uilondon.org/uore.htm

4. 1998 Uranium Institute Symposium paper "Waste Management in the Uranium Mining Industry" by Stan Frost, http://www.uilondon.org/sym/1998/frost.htm

5. UI Fact Sheet "Nuclear fuel cycle material balance" for 1000 Mwe LWR, B/01-BAL-10-97, http://www.uilondon.org/pdf/Balance.pdf

6. Uranium Information Centre Ltd Nuclear Issue Briefing Paper #3, http://www.uic.com.au/nip03.htm

7. Uranium Information Centre Ltd Nuclear Issue Briefing Paper #33, http://www.uic.com.au/nip33.htm

8. Nuclear energy site fuel cycle description for enrichment, http://axil.whatswhat.com/nuke/html/enrichment.html

9. WISE Environmental Impacts report, http://www.antenna.nl/wise/439-440/chapter3.html

10. Uranium Information Centre Ltd Nuclear Issue Briefing Paper #57, http://www.uic.com.au/nip57.htm

11. REPP The Environmental Imperative for Renewable Energy: An Update, http://www.repp.org/

12. Externalities of Energy, ExternE Externalities of Energy – National Implementation (1998), CIEMAT (ed.), http://externe.jrc.es/

13. The Social Costs of Electricity: Do the Numbers Add Up?, Krupnick and Burtraw, http://www.rff.org/CFDOCS/disc_papers/PDF_files/9630.pdf

14. World Bank proposed revised sustainable development indicators, http://lnweb18.worldbank.org/ESSD/essdext.nsf/44ByDocName/EnvironmentalIndicatorsCurrentInitiatives

15. Indicators of Sustainable Development proposed by United Nations Council on Sustainable Development, http://www.un.org/esa/sustdev/worklist.htm

16. Genuine Progress Indicator 1998 update, http://www.rprogress.org/projects/gpi/

17. "Coal Combustion: Nuclear Resource or Danger", Alex Gabbard, Oak Ridge National Laboratory, http://www.ornl.gov/ORNLReview/rev26-34/text/colmain.html

18. Environmental Working Group report on mercury emissions from coal plants, http://www.ewg.org/pub/home/reports/mercuryfalling/mercurypr.html

19. Results of EPA's estimates for national mercury emissions from coal-fired power plants, http://www.epa.gov/ttn/uatw/combust/utiltox/utoxpg.html

20. Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: *Stationary Point and Area Sources,* Fifth Edition, Environmental Protection Agency, http://www.epa.gov/ttn/chief/ap42/

21. National Air Polluant Emissions Trends 1998, US Environmental Protection Agency, http://www.epa.gov/ttn/chief/trends/trends98/browse.html

22. EPA's Global Warming Site: National Emissions - Carbon Dioxide, http://www.epa.gov/oppeoee1/globalwarming/publications/emissions/us2000/i

23. EPA's Protocol for Emissions Leak Estimates, http://www.epa.gov/ttn/chief/efdocs/lks95_ch.pdf

24. EPA's Emissions Inventory Improvement Program, http://www.epa.gov/ttnchie1/eiip/techreport/

25. REAP report on short-rotation forestry water use, http://www.reap.ca/Reports/SRF%20and%20the%20Water%20Problem.htm

26. Environment Canada generator water use, http://www.ec.gc.ca/water/en/manage/use/e_therm.htm

27. WISE Uranium Mine and Mill Resident Individual Dose Calculator, file:///C|/Data Files/Nuclear Enterprise/rdcmrh.html

28. St. Louis et al., Reservoir Surfaces…, BioScience V50No9

29. Energy, Environmental and Economics (E3) Handbook, US Department of Energy, Office of Industrial Technology, http://www.oit.doe.gov/e3handbook/

30. Santa Barbara County summary table of emission factors, http://www2.sbcapcd.org/eng/tech/frog_01.htm

31. Description Emissions Inventories for the Southern Appalachian Mountains Initiative, http://www.saminet.org/reports/AWMAeminv_50100.htm

32. Default Table of VOC Emissions Factors Used in the RAINS Model in Transport Sector, http://www.iiasa.ac.at/~rains/voc_review/tra_ef.html

33. "State-of-the-Art (SOTA) Manual for Boilers", Emissions, New Jersey Department of Environmental Protection Air Quality Permitting Program, July 1997, http://www.state.nj.us/dep/aqpp/downloads/sota/sota12.pdf

Appendix A.

Appendix A-1. Environmental Impacts

Table A-1.1. Potential Environmental Impacts.

ID	Source	Phase	Impact Type	Details	Disposition	Notes
1	Coal	Conversion	Material Discharged	CO_2	Included	
2	Coal	Conversion	Material Discharged	Particulates	Not included	Small relative to other particulate sources. EPA's "Updated Tier tables for AQ report, 1998" indicate that total fuel combustion (generation and non-generation uses) accounts for less than 10% of PM-10 and PM-2.5 emissions
3	Hydro-electric	Conversion	Material Discharged	Methane production from submerged vegetation		
4	Coal	Conversion	Material Discharged	NOx	Included	
5	Coal	Conversion	Material Discharged	SO_2	Included	
6	Coal	Conversion	Material Discharged	VOCs	Not included	Primary discharge from solvents and automobiles
7	Coal	Conversion	Material Discharged	Mercury vapor from combustion	Included	"Based on EPA's National Toxics Inventory, the highest emitters of mercury to the air include coal-burning power plants, municipal waste combustors, medical waste incinerators and hazardous waste combustors. Mercury emissions from these and other sources
8	Oil	Conversion	Material Discharged	CO_2	Included	
9	Oil	Conversion	Material Discharged	NOx	Included	
10	Oil	Conversion	Material Discharged	SO_2	Included	
11	Oil	Conversion	Material Discharged	Particulates	Not included	Small relative to other particulate sources. EPA's "Updated Tier tables for AQ report, 1998" indicate that total fuel combustion (generation and non-generation uses)

ID	Source	Phase	Impact Type	Details	Disposition	Notes
						accounts for less than 10% of PM-10 and PM-2.5 emissions
12	Oil	Conversion	Material Discharged	VOCs	Not included	Primary discharge from solvents and automobiles
13	Oil	Conversion	Material Discharged	Mercury vapor from combustion	Not included	Small relative to coal
14	Natural Gas	Conversion	Material Discharged	CO2	Included	
15	Natural Gas	Conversion	Material Discharged	NOx	Included	
16	Natural Gas	Conversion	Material Discharged	SO2	Not included	Small relative to coal
17	Natural Gas	Conversion	Material Discharged	Particulates	Not included	Small relative to other particulate sources. EPA's "Updated Tier tables for AQ report, 1998" indicate that total fuel combustion (generation and non-generation uses) accounts for less than 10% of PM-10 and PM-2.5 emissions
18	Natural Gas	Conversion	Material Discharged	VOCs	Not included	Primary discharge from solvents and automobiles
19	Natural Gas	Conversion	Material Discharged	Mercury vapor from combustion	Not included	Small relative to coal
20	Coal	Conversion	Footprint	Acid rain -> Damage to forests, crops, buildings		
21	Oil	Conversion	Footprint	Acid rain -> Damage to forests, crops, buildings		
22	Natural Gas	Conversion	Footprint	Acid rain -> Damage to forests, crops, buildings		
23	Coal	Conversion	Footprint	Nitrification/ eutrophica-tion		
24	Oil	Conversion	Footprint	Nitrification/ eutrophica-tion		
25	Natural Gas	Conversion	Footprint	Nitrification/ eutrophica-tion		
26	Biomass	Conversion	Material Discharged	CO2	Included	May be offset considering alternative fuel fate
27	Biomass	Conversion	Material Discharged	NOx	Included	Co-fired plants lower emission rates from coal

ID	Source	Phase	Impact Type	Details	Disposition	Notes
28	Biomass	Conversion	Material Discharged	SO_2	Included	Not significant for virgin fuel
29	Biomass	Conversion	Material Discharged	Particulates	Not included	Small relative to other particulate sources. EPA's "Updated Tier tables for AQ report, 1998" indicate that total fuel combustion (generation and non-generation uses) accounts for less than 10% of PM-10 and PM-2.5 emissions
32	Coal	Conversion	Material Discharged	Methane	Included	
33	Oil	Conversion	Material Discharged	Methane	Included	
34	Natural Gas	Conversion	Material Discharged	Methane	Included	
35	Natural Gas	Fuel Transporta-tion	Material Discharged	Methane	Included	
36	Oil	Exploration	Material Discharged	Methane		
37	Oil	Fuel Production	Material Discharged	Methane	Included	
38	Coal	Fuel Production	Material Discharged	Methane		
39	Geo-thermal	Conversion	Material Discharged	CO_2	Included	
40	Biomass	Fuel Production	Offset/ Coproduction	NOx		Decreases coal NOx emission by lowering temp.
41	Geo-thermal	Waste Disposal	Offset/ Coproduction	Zinc, mineral coproduc-tion		
42	Coal	Fuel Production	Footprint	Mining	Included	
43	Coal	Fuel Transporta-tion	Footprint	Railways		
44	Coal	Conversion	Footprint	Power plant	Included	
45	Oil	Fuel Production	Footprint	Oil field		
46	Oil	Fuel Transporta-tion	Footprint	Pipelines		
47	Oil	Conversion	Footprint	Power plant		
48	Natural Gas	Fuel Production	Footprint	Oil field		
49	Natural Gas	Fuel Transporta-tion	Footprint	Pipelines		

ID	Source	Phase	Impact Type	Details	Disposition	Notes
50	Natural Gas	Conversion	Footprint	Power plant		
51	Fission	Fuel Production	Footprint	Mining and milling		
52	Fission	Conversion	Footprint	Power plant		
53	Hydro-electric	Conversion	Footprint	Reservoir area		
54	Photo-voltaic	Conversion	Footprint	Collector field	Included	
55	Geo-thermal	Conversion	Footprint	Plant+ Steam field	Included	
56	Wind	Conversion	Footprint	Wind farm	Included	
57	Thermal solar	Conversion	Footprint			
58	Biomass	Fuel Production	Footprint	Crop area	Included	
59	Biomass	Conversion	Footprint	Power plant	Included	
60	Coal	Fuel Production	Resource Consumed	Water	Included	
61	Coal	Conversion	Resource Consumed	Water	Included	
62	Oil	Conversion	Resource Consumed	Water	Included	
63	Natural Gas	Conversion	Resource Consumed	Water	Included	
64	Fission	Conversion	Resource Consumed	Water	Included	
65	Biomass	Fuel Production	Resource Consumed	Water	Included	
66	Biomass	Conversion	Resource Consumed	Water	Included	
67	Coal	Fuel Production	Footprint	Storage/ tailings runoff		
69	Fission	Fuel Production	Footprint	Storage/ tailings runoff		
70	Wind	Conversion	Footprint	Turbines can kill birds		
71	Hydro-electric	Conversion	Footprint	Impede fish migration		
72	Hydro-electric	Conversion	Footprint	Alteration in temperature, oxygen content, volume of flow		
73	Coal	Conversion	Footprint	Thermal polution of reservior	Included	

ID	Source	Phase	Impact Type	Details	Disposition	Notes
74	Oil	Conversion	Footprint	Thermal polution of reservior		
75	Natural Gas	Conversion	Footprint	Thermal polution of reservior		
76	Fission	Conversion	Footprint	Thermal polution of reservior	Included	
77	Biomass	Conversion	Footprint	Thermal polution of reservior		
78	Coal	Waste Disposal	Material Discharged	Ash and sludge containing toxic metals	Included	
79	Oil	Waste Disposal	Material Discharged	Ash and sludge containing toxic metals		
80	Biomass	Waste Disposal	Material Discharged	Ash and sludge	Included	
81	Biomass	Conversion	Offset/ Coproduction	Waste incineration can reduce landfill requirements		
82	Photo-voltaic	Decom-missioning	Material Discharged	Heavy metals: Cd, Se	Not included	Small unit energy rate relative to alternatives
83	Fission	Fuel Production	Material Discharged	Mining, milling releases of Radon		
84	Fission	Conversion	Material Discharged	Unexpected fuel release		
85	Fission	Waste Disposal	Material Discharged	Transportation accident		
86	Fission	Waste Disposal	Material Discharged	Repository breach or leakage		
87	Fission	Decom-missioning	Footprint	LLW Disposal		
88	Fission	Decom-missioning	Material Discharged	LLW release from landfill		
89	Coal	Waste Disposal	Material Discharged	Radioactive components of ash and sludge		
90	Oil	Fuel Production	Material Discharged	CO_2 from flared gas	Not Included	Less than 1/2% of current US CO_2 emissions

ID	Source	Phase	Impact Type	Details	Disposition	Notes
91	Hydro-electric	Conversion	Material Discharged	CO_2 absorption loss from flooded plants		
92	Coal	Conversion	Material Discharged	CO_2 from limestone used to absorb pollutants	Not Included	Total limestone and dolomite use less than 0.2% of current US CO_2 emissions
93	Oil	Conversion	Material Discharged	CO_2 from limestone used to absorb pollutants	Not Included	Total limestone and dolomite use less than 0.2% of current US CO_2 emissions
94	Natural Gas	Conversion	Material Discharged	CO_2 from limestone used to absorb pollutants	Not Included	Total limestone and dolomite use less than 0.2% of current US CO_2 emissions
95	Oil	Fuel Production	Material Discharged	SO_4 during refining		
96	Natural Gas	Exploration	Footprint	Marine ecosystem disturbance		
97	Natural Gas	Fuel Transportation	Footprint	Pipeline explosion		
98	Fission	Fuel Production	Material Discharged	Indirect impacts due to conversion and enrichment energy		
99	Biomass	Fuel Production	Footprint	Soil depletion/ erosion		
100	Biomass	Fuel Transporta-tion	Material Discharged	Indirect impacts due to road repair energy/ materials		
101	Hydro-electric	Development	Material Discharged	Energy/ Materials required to construct dams		
102	Hydro-electric	Conversion	Footprint	Dam burst		
103	Wind	Development	Material Discharged	Energy/ materials required in turbine production	Not included	Small material amounts compared to other sources

ID	Source	Phase	Impact Type	Details	Disposition	Notes
104	Coal	Conversion	Footprint	Generator noise		
105	Coal	Fuel Trans-portation	Footprint	Transporta-tion accidents and fatalities, "unexpectedly major"		
106	Oil	Conversion	Footprint	Generator noise		
107	Oil	Fuel Trans-portation	Footprint	Transporta-tion accidents and fatalities		
108	Fission	Conversion	Footprint	Generator noise		
109	Fission	Fuel Trans-portation	Footprint	Transporta-tion accidents and fatalities		
110	Biomass	Conversion	Footprint	Generator noise		
111	Biomass	Fuel Trans-portation	Footprint	Transporta-tion accidents and fatalities		
112	Natural Gas	Conversion	Footprint	Generator noise		
113	Hydro-electric	Conversion	Footprint	Generator noise		
114	Geo-thermal	Conversion	Footprint	Generator noise		
115	Wind	Conversion	Footprint	Generator noise		
116	Thermal solar	Conversion	Footprint	Generator noise		
118	Coal	Conversion	Footprint	Visibility damages		
119	Oil	Conversion	Footprint	Visibility damages		
120	Natural Gas	Conversion	Footprint	Visibility damages		
121	Fission	Conversion	Footprint	Visibility damages		
122	Hydro-electric	Conversion	Footprint	Visibility damages		
123	Photo-voltaic	Conversion	Footprint	Visibility damages		
124	Geo-thermal	Conversion	Footprint	Visibility damages		
125	Wind	Conversion	Footprint	Visibility damages		
126	Thermal solar	Conversion	Footprint	Visibility damages		

ID	Source	Phase	Impact Type	Details	Disposition	Notes
127	Biomass	Conversion	Footprint	Visibility damages		
128	Fission	Conversion	Material Discharged	Dose to operators		
129	Fission	Waste Disposal	Material Discharged	Dose to MOP during transportation		
130	Biomass	Conversion	Material Discharged	Dioxins from waste incineration		
131	Biomass	Conversion	Material Discharged	Heavy metals from waste incineration		
132	Coal	Conversion	Material Discharged	Black smoke	Not included	Aesthetic rather than environmental burden
133	Oil	Conversion	Material Discharged	Black smoke	Not included	Aesthetic rather than environmental burden
134	Natural Gas	Conversion	Material Discharged	Black smoke	Not included	Aesthetic rather than environmental burden
135	Coal	Conversion	Material Discharged	Ozone		
136	Oil	Conversion	Material Discharged	Ozone		
137	Natural Gas	Conversion	Material Discharged	Ozone		
138	Coal	Fuel Production	Resource Consumed	Coal	Included	
139	Oil	Fuel Production	Resource Consumed	Oil		
140	Natural Gas	Fuel Production	Resource Consumed	Natural gas		
141	Fission	Fuel Production	Resource Consumed	Uranium		
142	Oil	Fuel Production	Material Discharged	Brine produced with product		
143	Natural Gas	Fuel Production	Material Discharged	Brine produced with product		
144	Fission	Fuel Production	Material Discharged	Mine tailings		
145	Fission	Fuel Production	Material Discharged	Mill tailings		
146	Coal	Fuel Production	Material Discharged	Mine tailings		
147	Biomass	Conversion	Material Discharged	Methane	Included	
148	Natural Gas	Fuel Production	Material Discharged	Methane	Included	
149	Fission	Waste Disposal	Material Discharged	Spent Fuel	Included	

Table A-1.2. Upper and Lower Limits for Emissions Factors.

Im-pact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
1	Material Discharged	CO2	MMTCE/ Quad	Coal	Conversion	25.72	25.72	Coal	Xport Use
1	Material Discharged	CO2	MMTCE/ Quad	Coal	Conversion	25.72	25.72	Coal	Ind Use
1	Material Discharged	CO2	MMTCE/ Quad	Coal	Conversion	25.72	25.72	Coal	Misc Use
1	Material Discharged	CO2	MMTCE/ Quad	Coal	Conversion	25.72	25.72	Coal	Power Prod
2	Material Discharged	Particulates	MMT/ Quad	Coal	Conversion	0.000494	0.235	Coal	Power Prod
3	Material Discharged	Methane production from sub-merged vegetation	MMTCE/ Quad/Year	Hydro-electric	Conversion	1.16	20.7	Hydro	Power Prod
4	Material Discharged	Nox	MMT/Quad	Coal	Conversion	0.0988	0.652	Coal	Xport Use
4	Material Discharged	Nox	MMT/Quad	Coal	Conversion	0.0988	0.652	Coal	Ind Use
4	Material Discharged	Nox	MMT/Quad	Coal	Conversion	0.0988	0.652	Coal	Misc Use
4	Material Discharged	Nox	MMT/Quad	Coal	Conversion	0.0988	0.652	Coal	Power Prod
5	Material Discharged	SO2	MMT/Quad	Coal	Conversion	0.613	3	Coal	Xport Use
5	Material Discharged	SO2	MMT/Quad	Coal	Conversion	0.613	3	Coal	Ind Use
5	Material Discharged	SO2	MMT/Quad	Coal	Conversion	0.613	3	Coal	Misc Use

Impact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
5	Material Discharged	SO2	MMT/Quad	Coal	Conversion	0.613	3	Coal	Power Prod
6	Material Discharged	VOCs	MMT/Quad	Coal	Conversion	0.00123	0.00227	Coal	Power Prod
7	Material Discharged	Mecury vapor from combus-tion	MT/Quad	Coal	Conversion	0.435	13	Coal	Xport Use
7	Material Discharged	Mecury vapor from combus-tion	MT/Quad	Coal	Conversion	0.435	13	Coal	Ind Use
7	Material Discharged	Mecury vapor from combus-tion	MT/Quad	Coal	Conversion	0.435	13	Coal	Misc Use
7	Material Discharged	Mecury vapor from combus-tion	MT/Quad	Coal	Conversion	0.435	13	Coal	Power Prod
8	Material Discharged	CO2	MMTCE/ Quad	Oil	Conversion	20.09	20.09	Oil	Xport Use
8	Material Discharged	CO2	MMTCE/ Quad	Oil	Conversion	20.09	20.09	Oil	Ind Use
8	Material Discharged	CO2	MMTCE/ Quad	Oil	Conversion	20.09	20.09	Oil	Misc Use
8	Material Discharged	CO2	MMTCE/ Quad	Oil	Conversion	20.09	20.09	Oil	Power Prod
9	Material Discharged	Nox	MMT/Quad	Oil	Conversion	0.0367	0.202	Oil	Xport Use
9	Material Discharged	Nox	MMT/Quad	Oil	Conversion	0.0329	0.181	Oil	Ind Use
9	Material Discharged	Nox	MMT/Quad	Oil	Conversion	0.0329	0.181	Oil	Misc Use

Impact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
9	Material Discharged	Nox	MMT/Quad	Oil	Conversion	0.0329	0.181	Oil	Power Prod
10	Material Discharged	SO2	MMT/Quad	Oil	Conversion	0.0934	1.03	Oil	Xport Use
10	Material Discharged	SO2	MMT/Quad	Oil	Conversion	0.0329	1.03	Oil	Ind Use
10	Material Discharged	SO2	MMT/Quad	Oil	Conversion	0.0934	1.03	Oil	Misc Use
10	Material Discharged	SO2	MMT/Quad	Oil	Conversion	0.0934	1.03	Oil	Power Prod
11	Material Discharged	Particulates	MMT/Quad	Oil	Conversion	0.000157	0.00596	Oil	Power Prod
12	Material Discharged	VOCs	MMT/Quad	Oil	Conversion	0.77	1.33	Oil	Xport Use
12	Material Discharged	VOCs	MMT/Quad	Oil	Conversion	0.00064	0.0064	Oil	Power Prod
14	Material Discharged	CO2	MMTCE/ Quad	Natural Gas	Conversion	14.47	14.47	Gas	Xport Use
14	Material Discharged	CO2	MMTCE/ Quad	Natural Gas	Conversion	14.47	14.47	Gas	Ind Use
14	Material Discharged	CO2	MMTCE/ Quad	Natural Gas	Conversion	14.47	14.47	Gas	Misc Use
14	Material Discharged	CO2	MMTCE/ Quad	Natural Gas	Conversion	14.47	14.47	Gas	Power Prod
15	Material Discharged	Nox	MMT/Quad	Natural Gas	Conversion	0.0445	0.0864	Gas	Ind Use
15	Material Discharged	Nox	MMT/Quad	Natural Gas	Conversion	0.0445	0.0864	Gas	Power Prod
18	Material Discharged	VOCs	MMT/Quad	Natural Gas	Conversion	0.000818	0.00545	Gas	Power Prod

Impact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
26	Material Discharged	CO2	MMTCE/ Quad	Biomass	Conversion	0	21.8	Com-bus-tibles	Power Prod
27	Material Discharged	Nox	MMT/Quad	Biomass	Conversion	0.0191	0.1	Com-bust-ibles	Power Prod
28	Material Discharged	SO2	MMT/Quad	Biomass	Conversion	0.00377	0.00377	Com-bust-ibles	Power Prod
29	Material Discharged	Partic-ulates	MMT/Quad	Biomass	Conversion	0.0235	0.55	Com-bust-ibles	Power Prod
32	Material Discharged	Methane	MMTCE/ Quad	Coal	Conversion	0.0604	0.0604	Coal	Xport Use
32	Material Discharged	Methane	MMTCE/ Quad	Coal	Conversion	0.0604	0.0604	Coal	Ind Use
32	Material Discharged	Methane	MMTCE/ Quad	Coal	Conversion	0.0604	0.0604	Coal	Misc Use
32	Material Discharged	Methane	MMTCE/ Quad	Coal	Conversion	0.0604	0.0604	Coal	Power Prod
33	Material Discharged	Methane	MMTCE/ Quad	Oil	Conversion	0.181	0.181	Oil	Xport Use
33	Material Discharged	Methane	MMTCE/ Quad	Oil	Conversion	0.181	0.181	Oil	Ind Use
33	Material Discharged	Methane	MMTCE/ Quad	Oil	Conversion	0.181	0.181	Oil	Misc Use
33	Material Discharged	Methane	MMTCE/ Quad	Oil	Conversion	0.181	0.181	Oil	Power Prod
34	Material Discharged	Methane	MMTCE/ Quad	Natural Gas	Conversion	0.0604	0.0604	Gas	Xport Use
34	Material Discharged	Methane	MMTCE/ Quad	Natural Gas	Conversion	0.0604	0.0604	Gas	Ind Use
34	Material Discharged	Methane	MMTCE/ Quad	Natural Gas	Conversion	0.0604	0.0604	Gas	Misc Use

Impact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
34	Material Discharged	Methane	MMTCE/ Quad	Natural Gas	Conversion	0.0604	0.0604	Gas	Power Prod
35	Material Discharged	Methane	MMTCE/ Quad	Natural Gas	Fuel Transportation	0.344	0.714	Gas	R2RX port
37	Material Discharged	Methane	MMTCE/ Quad	Oil	Fuel Production	0.0109	0.0725	Oil	Fuel Production
38	Material Discharged	Methane	MMTCE/ Quad	Coal	Fuel Production	0.035	0.88	Coal	Fuel Production
58	Footprint	Crop area	Km^2/Quad/Year	Biomass	Fuel Production	106500	163100	Combustibles	Power Prod
61	Resource Consumed	Water	Bm^3/Quad	Coal	Conversion	0.53	0.53	Coal	Power Prod
62	Resource Consumed	Water	Bm^3/Quad	Oil	Conversion	0.53	0.53	Oil	Power Prod
63	Resource Consumed	Water	Bm^3/Quad	Natural Gas	Conversion	0.53	0.53	Gas	Power Prod
64	Resource Consumed	Water	Bm^3/Quad	Fission	Conversion	0.52	0.52	Nuclear	Power Prod
65	Resource Consumed	Water	Bm^3/Quad	Biomass	Fuel Production	14.7	85	Combustibles	Power Prod
73	Footprint	Thermal polution of reservior	Bm^3/Quad	Coal	Conversion	26.5	41	Coal	Power Prod
74	Footprint	Thermal polution of reservior	Bm^3/Quad	Oil	Conversion	26.5	41	Oil	Power Prod
75	Footprint	Thermal polution of reservior	Bm^3/Quad	Natural Gas	Conversion	26.5	41	Gas	Power Prod
76	Footprint	Thermal polution of reservior	Bm^3/Quad	Fission	Conversion	32.8	60.1	Nuclear	Power Prod

Impact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
77	Footprint	Thermal polution of reservior	Bm^3/Quad	Biomass	Conversion	41	41	Combustibles	Power Prod
78	Material Discharged	Ash and sludge containing toxic metals	MMT/Quad	Coal	Waste Disposal	15900000	15900000	Coal	Power Prod
80	Material Discharged	Ash and sludge	MMT/Quad	Biomass	Waste Disposal	6200000	9010000	Combustibles	Power Prod
83	Material Discharged	Mining, milling releases of Radon	Ci/Quad	Fission	Fuel Production	0.946	54.1	Nuclear	Fuel Production
89	Material Discharged	Radioactive components of ash and sludge	Ci/Quad	Coal	Waste Disposal	186	186	Coal	Xport Use
89	Material Discharged	Radioactive components of ash and sludge	Ci/Quad	Coal	Waste Disposal	186	186	Coal	Ind Use
89	Material Discharged	Radioactive components of ash and sludge	Ci/Quad	Coal	Waste Disposal	186	186	Coal	Misc Use
89	Material Discharged	Radioactive components of ash and sludge	Ci/Quad	Coal	Waste Disposal	186	186	Coal	Power Prod

Impact ID	Impact Type ID	Details	Model Units	Source	Phase	Low Value	High Value	Fuel	Use
91	Material Discharged	CO2 generation and absorption loss from flooded plants	MMTCE/ Quad	Hydro-electric	Conversion	3.86	17.9	Hydro	Power Prod
138	Resource Consumed	Coal	MMT/Quad	Coal	Fuel Production	1.05E+08	1.05E+08	Coal	Fuel Produc-tion
147	Material Discharged	Methane	MMTCE/ Quad	Biomass	Conversion	1.81	1.81	Com-bus-tibles	Power Prod
148	Material Discharged	Methane	MMTCE/ Quad	Natural Gas	Fuel Production	0.288	0.55	Gas	Fuel Produc-tion
149	Material Discharged	Spent Fuel	Ci/Quad	Fission	Waste Disposal	0	9.43E+ 08	Nu-clear	Power Prod
42	Footprint	Mining	Km^2/Quad	Coal	Fuel Production	730.3	730.3	Coal	Fuel Produc-tion
44	Footprint	Power plant	Km^2/Quad/ Year	Coal	Conversion	231.1	231.1	Coal	Power Prod
47	Footprint	Power plant	Km^2/Quad/ Year	Oil	Conversion	231.1	231.1	Oil	Power Prod
50	Footprint	Power plant	Km^2/Quad/ Year	Natural Gas	Conversion	231.1	231.1	Gas	Power Prod
52	Footprint	Power plant	Km^2/Quad/ Year	Fission	Conversion	134	472	Nu-clear	Power Prod
53	Footprint	Reservoir area	Km^2/Quad/ Year	Hydro-electric	Conversion	13800	13800	Hydro	Power Prod
54	Footprint	Collector field	Km^2/Quad/ Year	Photo-voltaic	Conversion	1675	1675	Solar	Power Prod
56	Footprint	Wind farm	Km^2/Quad/ Year	Wind	Conversion	6700	15400	Wind	Power Prod

Appendix A-2. Model Variables

Table A-2.1. Model Variables.

Model Variable Name	Range	Descriptions/Source/Comments
Active_Stockpile_Option	R = Region	
Active_Stockpile_Time	R = Region	
Additional_wPu_Declared_Surplus	Region	
All_Region_Damages_1		
All_Region_Damages_2		
All_Region_Damages_3		
Assorted_fission_products_Generic		The Institute of Electrical Engineers at http://www.iee.org.uk/PAB/Env/ nucfuelcycl.htm
Assorted_fission_products_LWR		From UIC Australia. In spent fuel of 1000 kg the weight of assorted fission products.
Auxiliary_103	R = Region	
Auxiliary_88	R = Region	
Btu_to_GWae		EIA IEO 1999 Table B1 pp. 158 Btu to joules Btu x 1055.05585262 joules to megajoules j / 1,000,000 megajoules to kWhe mj / 3.6 kWhe to GWhe kWhe / 1,000,000 Since BTU in Quads (10^15) multiply by 10^15
By_Region_Damages_1	R = Region	
By_Region_Damages_2	R = Region	
By_Region_Damages_3	R = Region	
C_bu_Value	Reactor_Type	Albright, 1996 pp. 473 Table B.1
C_convlw_Factor		
C_convsw_Factor		
C_cvl_Value		
C_cvlw_Value		
C_cvsw_Value		
C_dayspy		
C_eec_Factor	Reactor_Type	
C_ef_Value	Reactor_Type	Albright, 1996 pp. 473 Table B.1
C_Elect_Fix_Shares	E = Elect_Fuel_Source	
C_Elect_Fuel_Share	Elect_Fuel_Source	
C_Elect_Not_Fix_Shares	E = Elect_Fuel_Source	
C_Elect_Rate_In	E = Elect_Fuel_Source	
C_Elect_Rate_Out	E = Elect_Fuel_Source	
C_Elect_Relative_Percent	E = Elect_Fuel_Source	
C_Elect_Relative_Shares	E = Elect_Fuel_Source	
C_Elect_Relative_Slider	E = Elect_Fuel_Source	

Model Variable Name	Range	Descriptions/Source/Comments
C_eworka_Factor	Reactor_Type	
C_eworkh_Factor	Reactor_Type	
C_ffablw_Factor	Reactor_Type	
C_ffabsw_Factor	Reactor_Type	
C_ffl_Value	Reactor_Type	
C_fflw_Value	Reactor_Type	
C_ffsw_Value	Reactor_Type	
C_Fuel_Demand	F = Fuel_Share_Total	
C_Ind_Fix_Shares	I = Ind_Fuel_Source	
C_Ind_Fuel_Share	I = Ind_Fuel_Source	
C_Ind_Not_Fix_Shares	I = Ind_Fuel_Source	
C_Ind_Rate_In	I = Ind_Fuel_Source	
C_Ind_Rate_Out	I = Ind_Fuel_Source	
C_Ind_Relative_Percent	I = Ind_Fuel_Source	
C_Ind_Relative_Shares	D = Ind_Fuel_Source	
C_Ind_Relative_Slider	I = Ind_Fuel_Source	
C_ml_Value		
C_na		
C_og_Value		
C_ogu3o8		
C_ore_Factor		
C_Other_Fix_Shares	O = Other_Fuel_Source	
C_Other_Fuel_Share	O = Other_Fuel_Source	
C_Other_Not_Fix_Shares	O = Other_Fuel_Source	
C_Other_Rate_In	O = Other_Fuel_Source	
C_Other_Rate_Out	O = Other_Fuel_Source	
C_Other_Relative_Percent	O = Other_Fuel_Source	
C_Other_Relative_Shares	O = Other_Fuel_Source	
C_Other_Relative_Slider	O = Other_Fuel_Source	
C_pa_Value	Reactor_Type	
C_Reactor_Fix_Shares	Reactor_Type	
C_Reactor_Not_Fix_Shares	Reactor_Type	
C_Reactor_Rate_In	Reactor_Type	
C_Reactor_Rate_Out	Reactor_Type	
C_Reactor_Relative_Percent	Reactor_Type	
C_Reactor_Relative_Percent_Total		
C_Reactor_Relative_Share	Reactor_Type	2000 IEO estimated share data from Table 18 pp. 104 in IEO 1999. 1999 IAEA MicroPris
C_Reactor_Relative_Shares	E = Reactor_Type	
C_Reactor_Relative_Slider	Reactor_Type	
C_Reactor_Shares_Percent_Total		
C_sfuel_Factor	Reactor_Type	
C_spec_Value	Reactor_Type	
C_swu_factor	Reactor_Type	

Model Variable Name	Range	Descriptions/Source/Comments
C_swusubna		
C_swusubpa	Reactor_Type	
C_swusubta	Reactor_Type	
C_ta_Value	Reactor_Type	
C_Tran_Fix_Shares	T = Tran_Fuel_Source	
C_Tran_Fuel_Share	T = Tran_Fuel_Source	
C_Tran_Not_Fix_Shares	T = Tran_Fuel_Source	
C_Tran_Rate_In	T = Tran_Fuel_Source	
C_Tran_Rate_Out	T = Tran_Fuel_Source	
C_Tran_Relative_Percent	T = Tran_Fuel_Source	
C_Tran_Relative_Shares	T = Tran_Fuel_Source	
C_Tran_Relative_Slider	T = Tran_Fuel_Source	
C_u_in_u308_Factor		
C_u3o8_Factor		
C_uf6n_factor		
C_uf6p_factor	Reactor_Type	
C_uf6t_factor	Reactor_Type	
C_uinuo2_Factor	R = Reactor_Type	
C_umt_Factor		
C_uninore_Factor		
C_uo2_Factor	Reactor_Type	
C_uu3o8		
C_uuf6		
C_uuo2		
C_wor_Value		
C_wrock_Factor		
CANDU_Pu_Content		
Capacity_for_Reprocessing_MOX	Region	What is the current worldwide capacity to reprocess spent fuel? Default value expresses current worldwide capacity and was taken from: IAEA. 1995. Options, experience and trends in spent nuclear fuel management. Technical report series no. 378. (Table 4, p.30) value given in table 4 has been adjusted from tons of heavy metal to tons of oxide. This capacity needs to be shared between all 3 commercial reprocessing activities (1st reprocessing, 2nd reprocessing, and MOX reprocessing). Can MOX be reprocessed in these same facilities? We assume yes until we find out otherwise. Here is the order in which the capacity is used: 1) 1st reprocessing, 2) 2nd reprocessing, 3) MOX reprocessing
Carbon_Factors		WEPS 2001 figures Coal, Oil, Gas
Carbon_per_Capita	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Carbon_per_GDP	R = Region	
Coal_Damages	Region,Common Impacts	
Coal_Impact_1		
Coal_Impact_2		
Coal_Impact_3		
Combustible_Damages	Region,Common Impacts	
Combustible_Impact_1		
Combustible_Impact_2		
Combustible_Impact_3		
Cool_SF_in_Storage	Region	Stock of cool spent fuel in storage that is available for reprocessing or for sending to a repository.
Cool_Spent_MOX	Region	Stock of MOX available for further reprocessing or disposal in a repository.
Cool_Spent_wMOX	Region	Stock of wMOX available for further reprocessing or disposal in a repository.
Cool_U_Spent_Fuel	Region	Stock of cool U spent fuel awaiting a second reprocessing. We assume the initial value to be zero. Conceivably, it could also be disposed of in a repository. The strategy of countries that reprocess has been to reprocess this fuel again and store the Pu and U.
CP_Liquid_Waste_Amt_C	R = Region, N = Reactor_Type	
CP_Solid_Waste_Amt_C	R = Region, N = Reactor_Type	
Current_Time		
deep_well_disposal_of_FSU_FP	Region	
Dismantlement_Rate_Policy	R = Region	
Dismantlements_2000	R = Region	
Dismantlements_End_Date	R = Region	
Dismantlements_Projection	R = Region	
Dismantlements_Projection_Sample	R = Region	
Dismantlements_Projection_Sample_In	R = Region	
Dismantlements_Projection_Sample_Out	R = Region	
Dismantlements_Ramp_Time	R = Region	
Dismantlements_Start_Time	R = Region	
Dismantlements_Target	R = Region	
Dismantlements_Target_China		
Dismantlements_Target_FSU		
Dismantlements_Target_OECD		
Dismantlements_Target_Previous	R = Region	
Dismantlements_Target_ROW		
Dismantlements_Target_USA		
El_Post_2020_Decay	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Elect_Coal	R = Region	NOTE: DOE EIA IEO 2001 includes Poland, Hungary, and the Czech Republic in Eastern Europe. They are part of the OECD. Therefore their contribution is suntracted fuels used in electricity production at a percentage determined by Total Electricity Consumption from EE. Their contribution is then added to our OECD total. Using these percents (1990-98) 0.494448073, 0.490743975, 0.416487235, 0.427800698, 0.453725359, 0.450063211, 0.447900936, 0.448120301, 0.451456311 as Poland, Hungary, and Czech Republic's consumption of fuels.
Elect_Coal_Proj	R = Region	DOE WEPS Electric Fuel Consumption.xls
Elect_EE_Gain	R = Region	
Elect_EE_Growth_Rate	R = Region	
Elect_Fuel_Percents	R = Region, E = Elect_Fuel_Source	
Elect_Fuel_Share	R = Region, E = Elect_Fuel_Source	
Elect_Fuel_Summary_by_Fuel	D = Elect_Fuel_Source	
Elect_Fuel_Summary_by_Region	R = Region	
Elect_Fuel_World_Total		
Elect_Fuels	R = Region, Elect_Fuel_Source	1990-1999 OECD Energy Balances, 2000-2020 DOE/IEO regional endpoints, 2021 -> trend based upon 2015-2020 growth rate
Elect_Fuels_Percent	R = Region, E = Elect_Fuel_Source	
Elect_Gas	R = Region	
Elect_Gas_Proj	R = Region	DOE WEPS Electric Fuel Consumption.xls
Elect_Hist	R = Region, E = Elect_Fuel_Source	
Elect_Hist_EE	R = Region	
Elect_Nuc_Demand_GWae	R = Region	
Elect_Nuc_Demand_Quads	R = Region	
Elect_Nuclear	R = Region	
Elect_Nuclear_Fuel_Demand	R = Region, E = Reactor_Type	
Elect_Nuclear_Proj	R = Region	DOE WEPS Electric Fuel Consumption.xls
Elect_Oil	R = Region	
Elect_Oil_Proj	R = Region	DOE WEPS Electric Fuel Consumption.xls
Elect_Proj_Drain	R = Region	
Elect_Proj_EE	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Elect_Renewable	R = Region	
Elect_Renewable_Proj	R = Region	DOE WEPS Electric Fuel Consumption.xls
Elect_Total_Fuel_Demand	R = Region, E = Elect_Fuel_Source	
Elect_Total_Fuels	R = Region	
Elect_Total_Proj_Fuel	R = Region, E = Elect_Fuel_Source	
Elect_User_Select	R = Region	
Elect_User_Selects	R = Region, E = Elect_Fuel_Source	
ElectProj	R = Region, E = Elect_Fuel_Source	
Emissions_Technology		
End_Date	R = Region	
Energy_Provided_by_HEU	R = Region	
Energy_Provided_by_MOX	Region	Amount of energy provided by burning MOX
Energy_Provided_by_Reprocessed_U	Region	Amount of energy provided by burning reprocessed U.
Enrichment_Factor		Number of tons of U metal reprocessed from spent fuel to make one ton of reprocessed fuel. reprocessed U fuel is about 4.5% U-235 (http://www.uic.com.au/nip42.htm) assuming the DU from this process is about the same as for natural uranium enrichment (0.3%), we calculate an enrichment factor of 8.4.
Environmental_Impact		
Excess_HEU_Proliferation_Index	Region	
Excess_HEU_Security_Function	Region	
Excess_HEU_Security_Parameter	Region	Effect of safeguards and security and material value
Excess_HUE_Proliferation_Cost		
Extraneous_Pu_Production_Kg	R = Region	Russian production of Pu
F_Elect_Fix_Shares	E = Elect_Fuel_Source	
F_Elect_Fuel_Share	Elect_Fuel_Source	
F_Elect_Not_Fix_Shares	E = Elect_Fuel_Source	
F_Elect_Rate_In	E = Elect_Fuel_Source	
F_Elect_Rate_Out	E = Elect_Fuel_Source	
F_Elect_Relative_Percent	E = Elect_Fuel_Source	
F_Elect_Relative_Shares	E = Elect_Fuel_Source	
F_Elect_Relative_Slider	E = Elect_Fuel_Source	
F_Fuel_Demand	F = Fuel_Share_Total	
F_Ind_Fix_Shares	I = Ind_Fuel_Source	
F_Ind_Fuel_Share	I = Ind_Fuel_Source	
F_Ind_Not_Fix_Shares	I = Ind_Fuel_Source	

Model Variable Name	Range	Descriptions/Source/Comments
F_Ind_Rate_In	I = Ind_Fuel_Source	
F_Ind_Rate_Out	I = Ind_Fuel_Source	
F_Ind_Relative_Percent	I = Ind_Fuel_Source	
F_Ind_Relative_Shares	D = Ind_Fuel_Source	
F_Ind_Relative_Slider	I = Ind_Fuel_Source	
F_Other_Fix_Shares	O = Other_Fuel_Source	
F_Other_Fuel_Share	O = Other_Fuel_Source	
F_Other_Not_Fix_Shares	O = Other_Fuel_Source	
F_Other_Rate_In	O = Other_Fuel_Source	
F_Other_Rate_Out	O = Other_Fuel_Source	
F_Other_Relative_Percent	O = Other_Fuel_Source	
F_Other_Relative_Shares	O = Other_Fuel_Source	
F_Other_Relative_Slider	O = Other_Fuel_Source	
F_Reactor_Fix_Shares	Reactor_Type	
F_Reactor_Not_Fix_Shares	Reactor_Type	
F_Reactor_Rate_In	Reactor_Type	
F_Reactor_Rate_Out	Reactor_Type	
F_Reactor_Relative_Percent	Reactor_Type	
F_Reactor_Relative_Percent_Total		
F_Reactor_Relative_Share	Reactor_Type	
F_Reactor_Relative_Shares	E = Reactor_Type	
F_Reactor_Relative_Slider	Reactor_Type	
F_Reactor_Shares_Percent_Total		
F_Tran_Fix_Shares	T = Tran_Fuel_Source	
F_Tran_Fuel_Share	T = Tran_Fuel_Source	
F_Tran_Not_Fix_Shares	T = Tran_Fuel_Source	
F_Tran_Rate_In	T = Tran_Fuel_Source	
F_Tran_Rate_Out	T = Tran_Fuel_Source	
F_Tran_Relative_Percent	T = Tran_Fuel_Source	
F_Tran_Relative_Shares	T = Tran_Fuel_Source	
F_Tran_Relative_Slider	T = Tran_Fuel_Source	
FF_Liquid_Waste_Amt_C	R = Region, N = Reactor_Type	
FF_Solid_Waste_Amt_C	R = Region, N = Reactor_Type	
First_Sep_PuO2	R = Region	
First_Sep_PuO2_Proliferation_Index	Region	
First_Sep_PuO2_Security_Function	Region	
First_Sep_PuO2_Security_Parameter	Region	Effect of safeguards and security and material value
First_Sep_PuO2Proliferation_Cost		
First_SF_Reprocessed_Materials	Region, MaterialType	Stock of reprocessed materials awaiting further disposition.
First_SF_Reprocessing	R = Region	
Fission_Product_Separation	R = Region	Rate that fission products are separated out from all 3 reprocessing activities.

Model Variable Name	Range	Descriptions/Source/Comments
FP_Vitrification	Region	
FP_Vitrification_Capacity	Region	Vitrification of civil high-level radioactive wastes first took place on an industrial scale in France in 1978. It is now carried out commercially at five facilities in Belgium, France and UK with capacity of 2500 canisters (1000 tonnes) per year. source -- NUCLEAR ELECTRICITY (Sixth edition, August 2000) Note: All material here remains Copyright Uranium Information Centre Ltd. CHAPTER 5, The "BACK END" of the NUCLEAR FUEL CYCLE 1000 t /4 = 250 t (where the vitrification factor is 4)
FP_Vitrification_Factor		Tons of vitrified fission products created for each ton of non-vitrified fission products. The vitrification factor accounts for the mass added by the glass or ceramic. Jim Krumhansl has a reference for this.
FSU_FP_to_well_injection	R = Region	
Fuel_2020	R = Region, E = Elect_Fuel_Source	
Fuel_at_Projection_Base	R = Region, E = Elect_Fuel_Source	
Fuel_Cycle_Net_Material_GWae	R = Region, N = Reactor_Type	
Fuel_Cycle_Net_Waste_GWae	R = Region, N = Reactor_Type	
Fuel_from_Back_End	R = Region	
Fuel_Shares_Growth_Post_2020	R = Region, E = Elect_Fuel_Source	
Fuel_Use_Damages	Region, CommonImpacts	
Fuels_at_2020	R = Region, E = Elect_Fuel_Source	
Fuels_at_Projection_Base	R = Region, E = Elect_Fuel_Source	
GCR_Pu_Content		
GDP	R = Region	
GDP_Custom_Defined	Region	
GDP_Custom_EP		End points for years 2005 to 2050 by 5 year increments - uses reference case EP
GDP_Flush	R = Region	
GDP_Growth_Percent	Region	
GDP_Growth_Rate	R = Region	
GDP_Historical	R = Region	
GDP_Historical_Growth	R = Region	DRI and S&P Historical GDP Growth 1990-2000 Last figure is the annual compounding growth rate

Model Variable Name	Range	Descriptions/Source/Comments
GDP_IEO_End_Points	R = Region	
GDP_IEO_High	R = Region	
GDP_IEO_Low	R = Region	
GDP_IEO_Projection	R = Region	
GDP_IEO_Reference	R = Region	
GDP_IEO_Reference_to_2020	R = Region	DOE EIA IEO 2001 Estimated growth rates using annual compounding
GDP_Init	R = Region	
GDP_Mod	R = Region	
GDP_Mod_Switch	R = Region	
GDP_Projection_to_2050	R = Region	Based on DOE EIA IEO 2001
GDP_Switch	Region	
GDP_User_Select	R = Region	
GenIV_Pu_Content		
GWae_Rate_WISE	R = Region, N = Reactor_Type	IEA Quadrillion BTU converted to GWae (GigaWatt years of electricity) divided by the WISE GWae factor. WISE calculations are essentially a specific value divided by its specific conversion factor. In our case GWae is the measure, so it is used to drive all other conversions. The energy portion of fuel produced through reprocessing is subtracted out. This facilitates all the WISE based calculations by reducing the total front Uranium requirements.
Gwae_Stock	R = Region, N = Reactor_Type	
GWhe_Amt_C	R = Region, N = Reactor_Type	
Gwhe_Produced	R = Region, N = Reactor_Type	
HEU_Awaiting_Disposal	R = Region	
HEU_Disposal_Agreement	R = Region	
HEU_Disposal_Process_Switch		
HEU_Disposal_Switch	R = Region	
HEU_from_Excess_to_Disposal	R = Region	
HEU_from_Parts_to_Disposal	R = Region	
HEU_Part_Constrained_Demand	R = Region	
HEU_Part_Fabrication_Rate	R = Region	
HEU_Part_Reserves	R = Region	www.brook.edu/FP/PROJECTS/Nucwcost/50.htm 50 Facts about US Nuclear Weapons Albright 1997, pp. 91. This should be considered representational.
HEU_Parts_Available_Total	R = Region	
HEU_Parts_New	R = Region	Assuming no pit production capability in the USA for 2000 to 2010.
HEU_Parts_Reserve_Available	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
HEU_Parts_Reuse	R = Region	
HEU_Parts_to_Reserve	R = Region	
HEU_Parts_to_Storage	R = Region	
HEU_Production	R = Region	For lack of better data left at 0 since no nations are currently building up stockpiles, should be increased if weapon production is wanted
HEU_Production_Rate	R = Region	
HEU_to_Disposal_Total	R = Region	
HEU_to_Final_Disposal	R = Region	
HEU_to_Final_Disposal_Total		
HEU_to_Weapon_Production	R = Region	906 kgs per ton
Historical_Dismantlements	R = Region	http://www.nrdc.org/nuclear/nudb/datab9.asp US1990-1996 http://www.nrdc.org/nuclear/nudb/datab10.asp Russia 1990-1996 http://www.nrdc.org/nuclear/nudb/datab19.asp - China, UK, Fr, 1990-1996, is total warheads, Stockpile, reserved and retired. We will call them stockpile http://www.nrdc.org/nuclear/tkstock/p1-52.pdf - All 1998 1997 China, UK and Fr Interpolated China 1999 BAS 5/6'99 UK, FR 1999, BAS 7/8'99
Historical_Reserve	R = Region	http://www.nrdc.org/nuclear/nudb/datab9.asp US1990-1996 http://www.nrdc.org/nuclear/nudb/datab10.asp Russia 1990-1996 http://www.nrdc.org/nuclear/nudb/datab19.asp - China, UK, Fr, 1990-1996, is total warheads, Stockpile, reserved and retired. We will call them stockpile http://www.nrdc.org/nuclear/tkstock/p1-52.pdf - All 1998 1997 China, UK and Fr Interpolated China 1999 BAS 5/6'99 UK, FR 1999, BAS 7/8'99
Historical_Weapons	R = Region	http://www.nrdc.org/nuclear/nudb/datab9.asp US1990-1996 http://www.nrdc.org/nuclear/nudb/datab10.asp Russia 1990-1996 http://www.nrdc.org/nuclear/nudb/datab19.asp - China, UK, Fr, 1990-1996, is total warheads, Stockpile, reserved and retired. We will call them stockpile http://www.nrdc.org/nuclear/tkstock/p1-52.pdf - All 1998 1997 China, UK and Fr Interpolated China 1999 BAS 5/6'99 UK, FR 1999, BAS 7/8'99

Model Variable Name	Range	Descriptions/Source/Comments
Hot_SF_in_Storage	Region	Spent fuel in local storage that has not cooled sufficiently to allow reprocessing or transfer to a repository. It is assumed that the initial amount of this stock is given by the initial rate of SF production times the number of years it takes for spent fuel to cool.
Hot_Spent_MOX	Region	Stock of hot spent MOX
Hot_Spent_wMOX	Region	Stock of hot spent MOX
Hot_to_Cool_Burned_MOX	R = Region	Delay that moves spent MOX from the hot stock to the cool stock
Hot_to_Cool_Burned_wMOX	R = Region	Delay that moves spent MOX from the hot stock to the cool stock
Hot_to_Cool_SF	R = Region	Amount of spent fuel that has cooled enough and becomes available each year for transfer to a repository or reprocessing facility.
Hot_to_Cool_U_Spent_Fuel	R = Region	Amount of U spent fuel that becomes cool enough for further reprocessing.
Hot_U_Spent_Fuel	Region	Stock of hot spent fuel produced by burning reprocessed U fuel. The initial stock is assumed to be the rate at which this spent fuel is produced times the cooling time.
HTGR_Switch		
Hydro_Damages	Region, Common Impacts	
Hydro_Impact_1		
Hydro_Impact_2		
Hydro_Impact_3		
Hydrogen_Energy_Efficiency		
Hydrogen_Trans	R = Region	
Impact_1	C = Common Impacts	
Impact_10	C = Common Impacts	
Impact_2	C = Common Impacts	
Impact_3	C = Common Impacts	
Impact_4	C = Common Impacts	
Impact_5	C = Common Impacts	
Impact_6	C = Common Impacts	
Impact_7	C = Common Impacts	
Impact_8	C = Common Impacts	
Impact_9	C = Common Impacts	
Ind_Coal	R = Region	OECD Energy Balances of OECD and Non-OECD Countries 1997-1998
Ind_Combust	R = Region	
Ind_El_Decay	R = Region	
Ind_El_Decay_Rate	R = Region	
Ind_El_Growth_Rate	R = Region	
Ind_Elect	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Ind_Elect_Demand	R = Region	
Ind_Fuel_Percents	R = Region, I = Ind_Fuel_Source	
Ind_Fuel_Sum	R = Region	
Ind_Fuel_Summary_by_Fuel	D = Ind_Fuel_Source	
Ind_Fuel_Summary_by_Region	R = Region	
Ind_Fuel_World_Total		
Ind_Fuels_Percent	R = Region, D = Ind_Fuel_Source	
Ind_Gas	R = Region	
Ind_Hist_El	R = Region	
Ind_Hist_Fuel_Share	R = Region, I = Ind_Fuel_Source	
Ind_Hist_Fuels	R = Region, I = Ind_Fuel_Source	
Ind_Hist_Total_Fuels	R = Region	
Ind_Normalized_Fuel_Percents	R = Region, D = Ind_Fuel_Source	
Ind_Oil	R = Region	
Ind_Proj_El	R = Region	
Ind_Rate_Start	R = Region, D = Ind_Fuel_Source	
Ind_Rate_Stop	R = Region, D = Ind_Fuel_Source	
Ind_Share	R = Region, D = Ind_Fuel_Source	
Ind_Share_Growth_Rates	R = Region, D = Ind_Fuel_Source	
Ind_Share_Post_2050_Growth_Rates	R = Region, D = Ind_Fuel_Source	
Ind_Total_Fuel_Demand	R = Region, I = Ind_Fuel_Source	
Ind_Total_Proj_Fuel	R = Region, I = Ind_Fuel_Source	
Ind_User_Select	Region	
Ind_User_Selects	R = Region, I = Ind_Fuel_Source	
Init_HEU_Part_Reserves	R = Region	
Init_Pit_Reserves	R = Region	
Initial_Cool_Spent_MOX	Region	Quantity of cool spent MOX at the start of the simulation. Assumed to be zero until we get data.
Initial_Cool_Spent_wMOX	Region	Quantity of cool spent wMOX at the start of the simulation.
Initial_HEU	R = Region	
Initial_Hot_Spent_MOX	Region	Quantity of burned but not yet cool MOX at the start of the simulation. Assumed zero, until we get data.

Model Variable Name	Range	Descriptions/Source/Comments
Initial_Hot_Spent_wMOX	Region	Quantity of burned but not yet cool wMOX at the start of the simulation.
Initial_Reprocessed_Materials	Region, Material Type	How much of this stuff has been reprocessed awaiting further disposition at the start of the model? What are the Russians doing with their spent fuel? It is estimated that the world inventory of separated civilian plutonium crossed the 100 t level during the early part of 1994. source -- Excerpt from the IAEA Annual Report for The imbalance over earlier years between the separation and use of plutonium had resulted in a global inventory of separated civil plutonium of about 160 tonnes at the end of 1996. The inventory may go up to 170 tonnes in the next couple of years before starting to decrease gradually to about 140 tonnes in 2015. Source -- Keynote Speech at IAEA International Symposium on Nuclear Fuel Cycle and Reactor Strategies: Adjusting to New Realities Vienna, 3 June 1997, by IAEA Director General Russia has 28 MT of separated Pu (inc. unburned MOX). we put all the Pu here and subtracted 28 from the world total of 170 to arrive at the OECD amount of 142. Sufficient U enrichment and fuel fab capacity argues against appreciable U stocks here. As for fission products, we have calculated their mass and considered them to have been vitrified at the start of the simulation. Therefore, this mass shows up in the intiial vitrified FP.
Initial_Reprocessing_Capacity	Region	What is the current worldwide capacity to reprocess spent fuel? Default value expresses current worldwide capacity and was taken from: IAEA. 1995. Options, experience and trends in spent nuclear fuel management. Technical report series no. 378. (Table 5, p.32) value given in table 5 has been adjusted from tons of heavy metal to tons of oxide. It is assumed almost that all this capacity resides in OECD nations. We need to check this. Russia separates up to 2 MT Pu per year (Oxford Research Group, p.8). Back calculating (assuming 1.15% Pu in SF) we get a reprocessing capacity of 175 MT/yr Japanese Rokkasho plant is scheduled to start operation in 2003 with a capacity of 800 MT/ yr.

Model Variable Name	Range	Descriptions/Source/Comments
Initial_SF_in_Storage	Region	Initial amount of spent fuel in storage. (We may need to subtract out the amount of hot SF in storage.) We have a value for the total worldwide amount. We still need to divvy up this total amount between the regions. The total amount of spent fuel accumulated worldwide at the end of 1997 was about 200,000 tHM. Assuming that part of the spent fuel to be generated in the future will be reprocessed, the amount to be stored by the year 2010 is projected to be about 230,000 tHM. source -- RISING NEEDS: Management of Spent Fuel at Nuclear Power Plants by Peter Dyck and Martin J. Crijns, IAEA
Initial_Terminal_Spent_Pu_in_Storage	Region	Initial stock of Pu metal in storage awaiting either breeders or AVLIS enrichment technology. We need a value for this. We assume 0. Very little, if any, spent MOX will have been reprocessed by the start of the simulation.
Initial_Terminal_Spent_U_in_Storage	Region	Initial stock of U metal in storage awaiting either breeders or AVLIS enrichment technology. We need a value for this. Until then we assume 0. This is not a big deal because this U is not of great environmental concern and it is not a proliferable material.
Initial_Unburned_MOX	Region	Amount of MOX produced and awaiting burning in a LWR at the start of the simulation. Assumed zero until we get data.
Initial_Unburned_wMOX	Region	Amount of wMOX produced and awaiting burning in a LWR at the start of the simulation.

Model Variable Name	Range	Descriptions/Source/Comments
Initial_Vitrified_FP_in_Storage	Region	This is the initial stock of vitrified FP in storage awaiting disposal at the start of the simulation. We need a value for this. In 1997, the annual spent fuel arisings from all types of reactors in nuclear power plants amounted to about 10,500 tonnes of heavy metal (tHM). The total amount of spent fuel accumulated worldwide at the end of 1997 was about 200,000 tHM and projections indicate that the cumulative amount generated by the year 2010 may surpass 340,000 tHM. About 130,000 tHM of spent fuel is presently being stored in at-reactor or AFR storage facilities awaiting either reprocessing or final disposal. Source -- RISING NEEDS: Management of Spent Fuel at Nuclear Power Plants by Peter Dyck and Martin J. Crijns, IAEA difference between SF arisings and total in storage in 1997 = 70,000 t. We assume that is the amount reprocessed. 10,000 t/y of which about 1/3 gets reprocessed yields another 10,000 t by 2000, giving 80,000 t total reprocessed by 2000. At 3% FP, gives 2400 t. We assume all this was vitrified. With a vitrification factor of 4, we get 9600 t of vitrified fission products.
Initial_wPu	Region	Initial inventory of wPu awaiting disposal. Early in 1996, the U.S. Department of Energy declared 38.2 metric tons of weapons plutonium to be surplus to the country's defense needs. Because more material is likely to be declared surplus, DOE studies on disposition were based on 50 MT. The Russian surplus, not formally declared, has been placed at 100 MT. http://axil.whatswhat.com/nuke/html/us_russia_plutonium.html
IO_World_Fuel	R = Region	
Kg_HEU_Per_Weapon		
Kg_per_Pit		Notional estimate
Level_11	R = Region, O = Other_Fuel_Source	
LWR_Pu_Content		Percent by reactor sub type 0.623485436 PWR 0.296305987 BWR 0.080208577 WVER
Maximum_Weapons_per_Year	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
MOX_Burn_Rate	Region	MOX burning is limited to approximately 1/3 of the fuel rods in a LWR. However, the current number of licensed reactors is small. This will be user defined. The default value could be the currently licensed amount (small) or the theoretical capacity of 1/3 total LWR burn rate (very large). Until we get a number, we'll use a large default value.
MOX_Burning	R = Region	Tons of MOX burned per year. Burned MOX supplies energy, consumes Pu stocks, and produces spent MOX.
MOX_Fab_Capacity	Region	Worldwide capacity to fabricate commercial MOX. The default is based on current capacity. All the capacity resides in the OECD nations. Current capacity is 50 MT/y according to Oxford Research Group report (p.47-48). [1060-160 -185]MTHM x 7% Pu] "The present global production capacity for thermal reactor MOX fuel is about 70 tonnes p.a. with almost 350 tonnes p.a. forecasted for 2000." Economics of the Nuclear Fuel Cycle, NEA/OECD, 1994 p31. 350 tons of MOX translates to a capacity to process 25 tons of Pu oxide (assuming 7% Pu in MOX) the slider should go much higher to allow for the case where there are no limitations imposed by capacity.
MOX_Fab_Rate	R = Region, S = MaterialType	Pulls plutonium (only) out of stock of reprocessed materials to be used in fabricating MOX fuel.
MOX_Factor		Tons of MOX created for each ton of reprocessed Pu oxide. Assumed 7% reactor grade Pu. http://www.uic.com.au/nip42.htm
MOX_Production	R = Region	Quantity of commercial MOX produced per year
MOX_Reprocessing	R = Region	
MRS_Capacity	Region	
MRS_Capacity_Remaining	Region	
MRS_Switch	Region	
MRS_to_Repositories	R = Region	
Net_Nuclear_Demand	R = Region, E = Reactor_Type	
New_HEU_Part_Demand	R = Region	
New_HEU_Parts_for_Weapons	R = Region	
New_Pit_Demand	R = Region	
New_Pits_for_Weapons	R = Region	
New_wPu_Awaiting_Disposal_by_Declared_Country	Region	

Model Variable Name	Range	Descriptions/Source/Comments
New_wPu_Awaiting_Disposal_by_Region	R = Region	Weapons grade Pu to be disposed of.
NG_Damages	Region,Common Impacts	
NG_Impact_1		
NG_Impact_2		
NG_Impact_3		
Nonvitrified_Fission_Products	R = Region	Stock of separated fission products awaiting vitrification.
Nuc_Damages	Region,Common Impacts	
Nuc_Impact_1		
Nuc_Impact_2		
Nuc_Impact_3		
O_Elect_Fix_Shares	E = Elect_Fuel_Source	
O_Elect_Fuel_Share	Elect_Fuel_Source	
O_Elect_Not_Fix_Shares	E = Elect_Fuel_Source	
O_Elect_Rate_In	E = Elect_Fuel_Source	
O_Elect_Rate_Out	E = Elect_Fuel_Source	
O_Elect_Relative_Percent	E = Elect_Fuel_Source	
O_Elect_Relative_Shares	E = Elect_Fuel_Source	
O_Elect_Relative_Slider	E = Elect_Fuel_Source	
O_Fuel_Demand	F = Fuel_Share_Total	
O_Ind_Fix_Shares	I = Ind_Fuel_Source	
O_Ind_Fuel_Share	I = Ind_Fuel_Source	
O_Ind_Not_Fix_Shares	I = Ind_Fuel_Source	
O_Ind_Rate_In	I = Ind_Fuel_Source	
O_Ind_Rate_Out	I = Ind_Fuel_Source	
O_Ind_Relative_Percent	I = Ind_Fuel_Source	
O_Ind_Relative_Shares	D = Ind_Fuel_Source	
O_Ind_Relative_Slider	I = Ind_Fuel_Source	
O_Other_Fix_Shares	O = Other_Fuel_Source	
O_Other_Fuel_Share	O = Other_Fuel_Source	
O_Other_Not_Fix_Shares	O = Other_Fuel_Source	
O_Other_Rate_In	O = Other_Fuel_Source	
O_Other_Rate_Out	O = Other_Fuel_Source	
O_Other_Relative_Percent	O = Other_Fuel_Source	
O_Other_Relative_Shares	O = Other_Fuel_Source	
O_Other_Relative_Slider	O = Other_Fuel_Source	
O_Reactor_Fix_Shares	Reactor_Type	
O_Reactor_Not_Fix_Shares	Reactor_Type	
O_Reactor_Rate_In	Reactor_Type	
O_Reactor_Rate_Out	Reactor_Type	
O_Reactor_Relative_Percent	Reactor_Type	
O_Reactor_Relative_Percent_Total		
O_Reactor_Relative_Share	Reactor_Type	2000 IEO estimated share data from Table 18 pp. 104 in IEO 1999. 1999 IAEA MicroPris

Model Variable Name	Range	Descriptions/Source/Comments
O_Reactor_Relative_Shares	E = Reactor_Type	
O_Reactor_Relative_Slider	Reactor_Type	
O_Reactor_Shares_Percent_Total		
O_Tran_Fix_Shares	T = Tran_Fuel_Source	
O_Tran_Fuel_Share	T = Tran_Fuel_Source	
O_Tran_Not_Fix_Shares	T = Tran_Fuel_Source	
O_Tran_Rate_In	T = Tran_Fuel_Source	
O_Tran_Rate_Out	T = Tran_Fuel_Source	
O_Tran_Relative_Percent	T = Tran_Fuel_Source	
O_Tran_Relative_Shares	T = Tran_Fuel_Source	
O_Tran_Relative_Slider	T = Tran_Fuel_Source	
Oil_Damages	Region, Common Impacts	
Oil_Impact_1		
Oil_Impact_2		
Oil_Impact_3		
Old_Fuel_from_Backend	R = Region	
Other_Coal	R = Region	
Other_El_Decay	R = Region	
Other_El_Decay_Rate	R = Region	
Other_El_Growth_Rate	R = Region	
Other_Elect	R = Region	
Other_Elect_Demand	R = Region	
Other_Fuel_Percents	R = Region, O = Other_Fuel_Source	
Other_Fuel_Summary_by_Fuel	D = Other_Fuel_Source	
Other_Fuel_Summary_by_Region	R = Region	
Other_Fuel_World_Total		
Other_Fuels_Percent	R = Region, O = Other_Fuel_Source	
Other_Gas	R = Region	
Other_Hist_El	R = Region	
Other_Hist_Fuel_Share	R = Region, O = Other_Fuel_Source	
Other_Hist_Fuels	R = Region,Other_Fuel_Source	
Other_Hist_Total_Fuels	R = Region	
Other_Normalized_Fuel_Percents	R = Region, O = Other_Fuel_Source	
Other_Oil	R = Region	
Other_Proj_El	R = Region	
Other_Resid	R = Region	
Other_Share_Growth_Rates	R = Region, O = Other_Fuel_Source	
Other_Share_Post_2050_Growth_Rates	R = Region, O = Other_Fuel_Source	
Other_Total_Fuel_Demand	R = Region, O = Other_Fuel_Source	

Model Variable Name	Range	Descriptions/Source/Comments
Other_Total_Proj_Fuel	R = Region, O = Other_Fuel_Source	
Other_User_Select	Region	
Other_User_Selects	R = Region, O = Other_Fuel_Source	
Percent_After_2nd_Burning	Material Type	Percentages of U, Pu, and fission products in reprocessed U spent fuel. We need to obtain these values. Operating assumption is that percentages are similar to spent fuel.
Percent_in_SF	Material Type	Percent of U, Pu, and fission products contained in spent fuel. These values assume 42.5GWd/t burnup from a typical PWR. Obtained from: Economics of the Nuclear Fuel Cycle, NEA/OECD, 1994 p29
Percent_in_Spent_MOX	Material Type	Proportion of U, Pu, and fission products in spent MOX. The current numbers are made up but vaguely reasonable based on simple back of the envelope calculations.
Percent_SF_to_Reprocessing	Region	Percentage of spent fuel going to repositories (versus reprocessing). the default value was obtained from: IAEA. 1995. Options, experience and trends in spent nuclear fuel management. Technical report series no. 378. (Table 1)
Percent_to_wMOX	Region	Percent of weapons Pu to be converted to MOX. (The rest will be mixed with fission products and vitrified.) User will be able to choose this proportion. Default values are based on a US strategy of converting about 70% of its surplus Pu into MOX while the Russians plan to turn all of their surplus Pu into MOX. http://axil.whatswhat.com/nuke/ html/us_russia_plutonium.html
Percent_wMOX_to_Reprocessing	Region	U.S. will be making MOX of 35 tons of wPu (50 tons total, 70% to MOX). Russia will be converting 100 tons into MOX. The Russians will reprocess their spent MOX while the U.S. will not. We assume that this current ratio holds over time. This value can be changed by the user.
Pit_Constrained_Demand	R = Region	
Pit_Fabrication_Rate	R = Region	
Pit_Proliferation_Cost		
Pit_Proliferation_Index	Region	

Model Variable Name	Range	Descriptions/Source/Comments
Pit_Reserves	R = Region	www.brook.edu/FP/PROJECTS/Nucwcost/50.htm 50 Facts about US Nuclear Weapons Albright 1997, pp. 91. This should be considered representational.
Pit_Security_Function	Region	
Pit_Security_Parameter	Region	Effect of safeguards and security and material value.
Pits_Available_Total	R = Region	
Pits_New	R = Region	Assuming no pit production capability in the USA for 2000 to 2010.
Pits_Reserve_Available	R = Region	
Pits_Reuse	R = Region	
Pits_to_Reserve	R = Region	
Pits_to_Storage	R = Region	
Pits_to_Tons_Conversion		4 kg Pu per pit (hypothetical).
Pits_Total	R = Region	
Plutonium_products_Generic		The Institute of Electrical Engineers at http://www.iee.org.uk/PAB/Env/nucfuelcycl.htm
Pop	R = Region	
Pop_Flush	R = Region	
Pop_Growth_Rate	R = Region	
Pop_Historical	R = Region	DRI and S&P Historical Population 1991-1998
Pop_Historical_Growth	R = Region	DRI and S&P Historical Population Growth 1990-2000
Pop_IEO_High	Region	
Pop_IEO_Low	Region	
Pop_IEO_Reference	R = Region	
Pop_Init	R = Region	
Pop_Projection	R = Region	
portion_to_disposal	Region	
portion_to_reprocessing	Region	
Post_2020_Fuel_Demand	R = Region, E = Elect_Fuel_Source	
Post_2020_Fuel_Drain	R = Region, E = Elect_Fuel_Source	
Post_2020_Fuels	R = Region, E = Elect_Fuel_Source	
Projection_Base		
Proportion_to_Vitrification	Region	Portion of wPu that will be vitrified.
Proportion_to_wMOX	Region	Portion of wPu that will be made into MOX
Pu_Awaiting_Disposal	R = Region	
Pu_Disposal_Agreement	R = Region	
Pu_Disposal_Process_Switch		
Pu_Disposal_Switch	R = Region	
Pu_from_Excess_to_Disposal	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Pu_from_Pits_to_Disposal	R = Region	
Pu_in_Pits	R = Region	
Pu_in_Pits_Total		
Pu_in_SF_LWR	R = Region, N = Reactor_Type	
Pu_in_spent_fuel_etc	Region	This calculation gives the amount of Pu tied up in spent fuel, spent MOX, and vitrified with fission products. Without access to better data, it has been assumed that: 1. Spent, reprocessed uranium fuel looks a lot like spent fuel 2. The guestimate of Pu in spent wMOX is reasonable 3. Commercial spent MOX looks a lot like spent wMOX
Pu_in_Weapons	R = Region	1000 in divisor to convert to tons
Pu_in_Weapons_Total		1000 in divisor to convert to tons
Pu_metal_to_Weapon_Production	R = Region	906 kgs per ton
Pu_Separated_Initial	R = Region	USA: Albright 1997, pp. 45 Table 3.5 (weapons grade plutonium declared as excess by the US DOE Secretary) Russia: Albright 1997, pp. 58 Table 3.12 China: Great Britain: Albright 1997, pp. 65 Table 3.13 France: Albright 1997, pp. 68 Table 3.14 Israel: India: Pakistan:
Pu_to_Disposal_Total	R = Region	
Pu_to_Final_Disposal	R = Region	
Pu_to_Final_Disposal_Total		
Pu_to_MOX	R = Region, S = MaterialType	
Pu_transfer_from_FSU	R = Region	
Pu_transfer_quantity		
Pu_transfer_switch		
Pu_transfer_to_USA	R = Region	
Pu_Weapons_Grade_Production	R = Region	Plutonium production is initiated when: The sum of Startegic pits and separated Pu is less than the Weapons Requirement in that case the difference times kilograms per pit is produced.
R_Elect_Fix_Shares	E = Elect_Fuel_Source	
R_Elect_Fuel_Share	Elect_Fuel_Source	
R_Elect_Not_Fix_Shares	E = Elect_Fuel_Source	
R_Elect_Rate_In	E = Elect_Fuel_Source	
R_Elect_Rate_Out	E = Elect_Fuel_Source	
R_Elect_Relative_Percent	E = Elect_Fuel_Source	
R_Elect_Relative_Shares	E = Elect_Fuel_Source	
R_Elect_Relative_Slider	E = Elect_Fuel_Source	
R_Fuel_Demand	F = Fuel_Share_Total	
R_Ind_Fix_Shares	I = Ind_Fuel_Source	
R_Ind_Fuel_Share	I = Ind_Fuel_Source	

Model Variable Name	Range	Descriptions/Source/Comments
R_Ind_Not_Fix_Shares	I = Ind_Fuel_Source	
R_Ind_Rate_In	I = Ind_Fuel_Source	
R_Ind_Rate_Out	I = Ind_Fuel_Source	
R_Ind_Relative_Percent	I = Ind_Fuel_Source	
R_Ind_Relative_Shares	D = Ind_Fuel_Source	
R_Ind_Relative_Slider	I = Ind_Fuel_Source	
R_Other_Fix_Shares	O = Other_Fuel_Source	
R_Other_Fuel_Share	O = Other_Fuel_Source	
R_Other_Not_Fix_Shares	O = Other_Fuel_Source	
R_Other_Rate_In	O = Other_Fuel_Source	
R_Other_Rate_Out	O = Other_Fuel_Source	
R_Other_Relative_Percent	O = Other_Fuel_Source	
R_Other_Relative_Shares	O = Other_Fuel_Source	
R_Other_Relative_Slider	O = Other_Fuel_Source	
R_Reactor_Fix_Shares	Reactor_Type	
R_Reactor_Not_Fix_Shares	Reactor_Type	
R_Reactor_Rate_In	Reactor_Type	
R_Reactor_Rate_Out	Reactor_Type	
R_Reactor_Relative_Percent	Reactor_Type	
R_Reactor_Relative_Percent_Total		
R_Reactor_Relative_Share	Reactor_Type	
R_Reactor_Relative_Shares	E = Reactor_Type	
R_Reactor_Relative_Slider	Reactor_Type	
R_Reactor_Shares_Percent_Total		
R_Tran_Fix_Shares	T = Tran_Fuel_Source	
R_Tran_Fuel_Share	T = Tran_Fuel_Source	
R_Tran_Not_Fix_Shares	T = Tran_Fuel_Source	
R_Tran_Rate_In	T = Tran_Fuel_Source	
R_Tran_Rate_Out	T = Tran_Fuel_Source	
R_Tran_Relative_Percent	T = Tran_Fuel_Source	
R_Tran_Relative_Shares	T = Tran_Fuel_Source	
R_Tran_Relative_Slider	T = Tran_Fuel_Source	
Ramp_Time	R = Region	
RBMK_Pu	R = Region, N = Reactor_Type	Albright, 1996 pp. 478
Reactor_Type_CANDU	R = Region	IAEA 1999 MicroPRIS
Reactor_Type_GCR	R = Region	IAEA 1999 MicroPRIS
Reactor_Type_GenIV	R = Region	
Reactor_Type_HTGR	R = Region	IAEA 1999 MicroPRIS
Reactor_Type_LWR	R = Region	IAEA 1999 MicroPRIS
Reactor_Type_Percents	R = Region, N = Reactor_Type	
Reactor_Type_RBMK	R = Region	IAEA 1999 MicroPRIS
Reactor_Type_Share	R = Region, N = Reactor_Type	
Reactor_User_Select	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Reactor_User_Selects	R = Region, E = Reactor_Type	
Region_Selection_1	Region	
Region_Selection_2	Region	
Region_Selection_3	Region	
Regional_Repository_Capacity	R = Region	
Renewable_Allocations	Region, Renewables	Derived from OECD data for 1998 production, excluding geothermal production.
Renewable_Impact_1		
Renewable_Impact_2		
Renewable_Impact_3		
Repository_Capacity	Region, Repositories	Place holders.
Repository_Capacity_Remaining	Region, Repositories	Calculates the amount of room left in the repository.
Reprocessed_MOX_Materials	Region, MaterialType	Stocks from MOX reprocessing.
Reprocessed_U_Fuel_Burning	R = Region	Tons of reprocessed U fuel burned per year. Burned reprocessed U supplies energy, consumes reprocessed U stocks, and produces spent fuel.
Reprocessed_U_Fuel_Production	R = Region	Tons of reprocessed U fuel produced per year
Reprocessing_Capacity	R = Region	
Reserve_2000	R = Region	
Reserve_End_Date	R = Region	
Reserve_Projection	R = Region	
Reserve_Projection_Sample	R = Region	
Reserve_Projection_Sample_In	R = Region	
Reserve_Projection_Sample_Out	R = Region	
Reserve_Ramp_Time	R = Region	
Reserve_Start_Time	R = Region	
Reserve_Target	R = Region	
Reserve_Target_China		
Reserve_Target_FSU		
Reserve_Target_OECD		
Reserve_Target_Previous	R = Region	
Reserve_Target_ROW		
Reserve_Target_USA		
Reserve_Weapons_Policy	R = Region	
Round_Active_Stockpile	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Second_Reprocessing_Capacity	Region	What is the current worldwide capacity to reprocess spent fuel? Default value expresses current worldwide capacity and was taken from: IAEA. 1995. Options, experience and trends in spent nuclear fuel management. Technical report series no. 378. (Table 4, p.30) value given in table 4 has been adjusted from tons of heavy metal to tons of oxide. This capacity needs to be shared between all 3 commercial reprocessing activities (1st reprocessing, 2nd reprocessing, and MOX reprocessing). Can MOX be reprocessed in these same facilities? We assume yes until we find out otherwise. here is the order in which the capacity is used: 1st reprocessing, 2) 2nd reprocessing, 3) MOX reprocessing.
Second_SF_Reprocessed_Materials	Region, Material Type	Stocks from the second reprocessing.
Second_SF_Reprocessing	R = Region	
Separated_MOX_Reprocessing	R = Region, S = Material Type	Rate at which cool spent commercial MOX is reprocessed.
Separated_SF_1st_Reprocessing	R = Region, S = Material Type	Rate at which spent fuel gets reprocessed.
Separated_SF_2nd_Reprocessing	R = Region, S = Material Type	Rate at which the second reprocessing occurs.
SF_Cooling_Time		We need to know time spent fuel must cool before it can be reprocessed or placed in a repository. This model assumes that this time is the same for all reprocessing activities as well as time to wait to place in a repository. If this is not right, we will need to split this out into several variables. At present, we assume 10 years.
SF_in_local_storage	Region	
SF_in_Repositories_by_Region	R = Region	
SF_to_Repositories	Region	Portion of spent fuel that will be stored and sent to a repository. "once through" fuel cycle (no reprocessing).
SF_to_Reprocessing	Region	Portion of spent fuel that will be reprocessed.
SF_transfer_from_OECD	R = Region	
SF_transfer_quantity		
SF_transfer_switch		
SF_transfer_to_FSU	R = Region	
Solar_Damages	Region, Common Impacts	
Solar_Impact_1		
Solar_Impact_2		
Solar_Impact_3		

Model Variable Name	Range	Descriptions/Source/Comments
Spent_Fuel	Region	
Spent_Fuel_Destined_for_Disposal	Region	
Spent_Fuel_Destined_for_Reprocessing	Region	Stock of spent fuel that will be reprocessed. The initial stock is predicated on the assumption that there is not a backlog of spent fuel in the system. This may or may not be a reasonable assumption for Europe, but is almost certainly a poor assumption for Russia.
Spent_Fuel_in_MRS	Region	
Spent_Fuel_in_Repositories	Region, Repositories	Stock showing the total amount of SF and FP contained in repositories. Since no repositories are currently licensed to operate, the initial value is zero.
Spent_Fuel_per_Region	R = Region	
Spent_Fuel_Proliferation_Cost		
Spent_Fuel_Proliferation_Index	Region	
Spent_Fuel_Rate	R = Region	Amount of new spent fuel produced given the demand for electricity produced from nuclear energy. The amount of electricity produced by burning MOX and reprocessed U fuel is subtracted from the total demand for nuclear energy.
Spent_Fuel_Rate_C	R = Region, N = Reactor_Type	
Spent_Fuel_Security_Function	Region	
Spent_Fuel_Security_Parameter	Region	Effect of safeguards and security and material value
Spent_wMOX_to_Repository	Region	Portion of spent weapons MOX that is being sent to a repository.
Spent_wMOX_to_Reprocessing	Region	Portion of spent weapons MOX being reprocessed.
Start_Dismantlements	R = Region	
Start_Reserves	R = Region	
Start_Time	R = Region	
Start_Weapons	R = Region	
Sum_Excess_HEU_Proliferation_Index		
Sum_First_Sep_PuO2_Proliferation_Index		
Sum_Pit_Proliferation_Index		
Sum_Pits		
Sum_Spent_Fuel_Proliferation_Index		
Sum_Terminal_Reprocessed_Pu_Proliferation_Index		
Sum_Unburned_C_MOX_Proliferation_Index		
Sum_US_Fuels		
Sum_Weapon_Proliferation_Index		

Model Variable Name	Range	Descriptions/Source/Comments
Sum_Weapons		
Sum_WGPu_Proliferation_Index		
Sum_wMOX_Proliferation_Index		
Summed_Impacts	C = Common Impacts	
Summed_Impacts_1	C = Common Impacts	
Summed_Impacts_10	C = Common Impacts	
Summed_Impacts_11	C = Common Impacts	
Summed_Impacts_12	C = Common Impacts	
Summed_Impacts_13	C = Common Impacts	
Summed_Impacts_14	C = Common Impacts	
Summed_Impacts_15	C = Common Impacts	
Summed_Impacts_16	C = Common Impacts	
Summed_Impacts_17	C = Common Impacts	
Summed_Impacts_18	C = Common Impacts	
Summed_Impacts_19	C = Common Impacts	
Summed_Impacts_2	C = Common Impacts	
Summed_Impacts_20	C = Common Impacts	
Summed_Impacts_21	C = Common Impacts	
Summed_Impacts_22	C = Common Impacts	
Summed_Impacts_23	C = Common Impacts	
Summed_Impacts_24	C = Common Impacts	
Summed_Impacts_25	C = Common Impacts	
Summed_Impacts_26	C = Common Impacts	
Summed_Impacts_3	C = Common Impacts	
Summed_Impacts_4	C = Common Impacts	
Summed_Impacts_5	C = Common Impacts	
Summed_Impacts_6	C = Common Impacts	
Summed_Impacts_7	C = Common Impacts	
Summed_Impacts_8	C = Common Impacts	
Summed_Impacts_9	C = Common Impacts	
Surplus_WG_Pu	R = Region	
SWU_Amt_C	R = Region, N = Reactor_Type	
Terminal_Reprocessed_Pu_in_ Storage	R = Region	Total stock of Pu metal in storage (initial + reprocessed MOX + second reprocessing of U fuel) awaiting either breeders or AVLIS enrichment technology.
Terminal_Reprocessed_Pu_ Proliferation_Cost		
Terminal_Reprocessed_Pu_ Proliferation_Index	Region	
Terminal_Reprocessed_Pu_Security_ Function	Region	
Terminal_Reprocessed_Pu_Security_ Parameter	Region	Effect of safeguards and security and material value

Model Variable Name	Range	Descriptions/Source/Comments
Terminal_Reprocessed_U_in_Storage	R = Region	Total stock of U metal in storage (initial + reprocessed MOX + second reprocessing of U fuel) awaiting either breeders or AVLIS enrichment technology.
Time_in_Stockpile		Years in stockpile (or the nominal life of a weapon).
Time_of_wMOX_Fab	Region	Time_of_wMOX_Fab These are the years in which the US and Russian plants to fabricate MOX from weapons Pu become operational. In the U.S., the DOE is planning to build a facility to do this since there are no domestic commercial MOX facilities. Conversion of the pits into plutonium oxide for disposition could begin by 2005 and disposition of non-pit plutonium could begin about 2004, according to DOE. http://axil.whatswhat.com/nuke/html/us_russia_plutonium.html SpentFUEL, 3/29/99 (Vol. 5, No. 249): "U.S. DOE Awards $130 Million Pu Disposition Contract To Duke-COGEMA-Stone & Webster Team" The U.S. Department of Energy last week signed a contract to support disposition of surplus plutonium from dismantled warheads. DOE identified the Savannah River Site as the preferred site for the mixed oxide fuel fabrication facility. The European vendors are willing to build a fuel fabrication plant in Russia for the plutonium disposition project, but in this case, the problem is how to finance it. At a plutonium disposition project, but in this case, the problem is how to finance it. At a meeting of government plutonium experts in November 1996, a team comprised of COGEMA, Siemens, and Russia's Ministry of Atomic Energy (MINATOM) announced a three-phase plan for a fabrication plant. The feasibility and basic design phase would last from January to June1998, followed by construction and then operation by MINATOM. The plan is to build the facility and burn 1,300 kilograms of plutonium annually in five Russian reactors.

Model Variable Name	Range	Descriptions/Source/Comments
(continued from previous page) Time_of_wMOX_Fab	Region	http://axil.whatswhat.com/nuke/html/mox_russ.html Oxford Research Group report (p.37) says MOX plant is planned to go online in 2007. Step function gives time that the Russian and the US plant become operational. Have assumed that both plants turn on in the same year (the year the US plant is scheduled to come online). We can change this as more data becomes available. In the interim, the user can change the value with a slider.
Time_to_Acquire_Facility		
Time_to_Acquire_Personnel		
Time_to_Acquire_Tooling		
Time_to_Convet_Pu_to_MOX		
Time_to_Vitrify_Pu		
To_Repositories	R = Region	
To_Storage	R = Region	
total_1st_reprocessed_Pu		
Total_Carbon_Regionally	Region	Million metric tons Carbon
Total_Coal_Carbon	R = Region	
Total_Elect_Demand	R = Region	
Total_Gas_Carbon	R = Region	
Total_HEU_Disposed	R = Region	
Total_Impact_1		
Total_Impact_2		
Total_Impact_3		
Total_Material_Destined_for_Repositories	Region	
Total_New_Fuel_Burned	R = Region, E = Reactor_Type	
Total_Nuc_Fuel_Demand	R = Region, N = Reactor_Type	
Total_Oil_Carbon	R = Region	
Total_Pu_Disposed	R = Region	
total_Pu_in_spent_fuel_etc		
total_repository_capacity		
Total_Separated_Reactor_Pu	R = Region	
Total_SF_in_local_storage		
total_SF_in_MRS		
total_SF_in_repositories		
Total_SF_to_Repositories	R = Region	
Total_Spent_Fuel_Rate		
Total_Spent_wMOX_to_Repository	R = Region	
Total_Surplus_HEU	R = Region	
Total_Surplus_WGPu	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
total_terminal_reprocessed_Pu_in_storage		
Total_Vitrified_FP	R = Region	
Total_Vitrified_wPu	R = Region	
Total_Weapons_Demand	R = Region	
Total_Weapons_Supply	R = Region	
total_wPu_awaiting_processing		
Tran_All_Other_Proj_Share	R = Region	WEPS 2001
Tran_Combust	R = Region	
Tran_EI_Decay	R = Region	Set September 7, 2001 through trial and error.
Tran_EI_Decay_Rate	R = Region	
Tran_EI_Growth_Rate	R = Region	
Tran_EI_Post_2020_Decay	R = Region	DOE IEO Post 2020 calculated from 2015 to 2020 World E/GDP per Region
Tran_Elect	R = Region	
Tran_Elect_Demand	R = Region	
Tran_Fuel_Percents	R = Region, T = Tran_Fuel_Source	
Tran_Fuel_Sum	R = Region	
Tran_Fuel_Summary_by_Fuel	D = Tran_Fuel_Source	
Tran_Fuel_Summary_by_Region	R = Region	
Tran_Fuel_World_Total		
Tran_Fuels_Percent	R = Region, T = Tran_Fuel_Source	
Tran_Gas	R = Region	
Tran_Hist_EI	R = Region	
Tran_Hist_Fuel_Share	R = Region, T = Tran_Fuel_Source	
Tran_Hist_Fuels	R = Region, Tran_Fuel_Source	
Tran_Hist_Total_Fuels	R = Region	
Tran_Hydrogen	R = Region	
Tran_Hydrogen_Demand	R = Region	
Tran_Nuc_Demand_GWae	R = Region	
Tran_Nuc_for_Hydrogen	R = Region	
Tran_Nuclear_for_Hydrogen_Sum		
Tran_Nuclear_Fuel_Demand	R = Region	
Tran_Oil	R = Region	
Tran_Oil_Proj_Share	R = Region	WEPS 2001
Tran_Proj_EI	R = Region	
Tran_Rate_Start	R = Region, O = Other_Fuel_Source	
Tran_Rate_Stop	R = Region, O = Other_Fuel_Source	
Tran_Total_Fuel_Demand	R = Region, T = Tran_Fuel_Source	

Model Variable Name	Range	Descriptions/Source/Comments
Tran_Total_Proj_Fuel	R = Region, T = Tran_Fuel_Source	
Tran_User_Select	Region	
Tran_User_Selects	R = Region, T = Tran_Fuel_Source	
Transfer_back_to_Reserve	Region	
Transfer_back_to_Stockpile	R = Region	
Transfer_Rate_to_MRS		
Transfer_Rate_to_Repositories		Expected rate of transfer from local storage to repositories. For Yucca Mt., it is expected to take about 25 years to fill the repository. (insights of Nick Francis and Mike Itamura.) this gives us a transfer rate of about 5000 tons/yr (70,000 ton capacity / 25 yr). We assume that all repositories have similar transfer rates. The value can be changed by the user.
Transfer_to_Dismantlement	R = Region	
Transfer_to_Repositories	R = Region, S = Repositories	
Transfer_to_Reserve	R = Region	
Transfer_to_Retired	R = Region	
Treaty	R = Region	
U_Elect_Fix_Shares	E = Elect_Fuel_Source	
U_Elect_Fuel_Share	Elect_Fuel_Source	
U_Elect_Not_Fix_Shares	E = Elect_Fuel_Source	
U_Elect_Rate_In	E = Elect_Fuel_Source	
U_Elect_Rate_Out	E = Elect_Fuel_Source	
U_Elect_Relative_Percent	E = Elect_Fuel_Source	
U_Elect_Relative_Shares	E = Elect_Fuel_Source	
U_Elect_Relative_Slider	E = Elect_Fuel_Source	
U_Enrich_and_Fuel_Fab_Capacity	Region	This is put in mostly for symmetry with the MOX fuel fab capacity. However, we expect no limitations in this regard. Let's just put in a very high number here and not give the user a slider to play with.
U_Fab_Rate	R = Region, S = Material Type	Pulls uranium (only) out of stock of reprocessed materials to be used in fabricating new U fuel.
U_Fuel_Burn_Rate	Region	In the absence of any technical reason that might limit the burning of this fuel, this number should be set high so that all available stocks are burned each year
U_Fuel_Demand	F = Fuel_Share_Total	
U_in_U3O8_Amt_C	R = Region, N = Reactor_Type	
U_Ind_Fix_Shares	I = Ind_Fuel_Source	
U_Ind_Fuel_Share	I = Ind_Fuel_Source	
U_Ind_Not_Fix_Shares	I = Ind_Fuel_Source	

Model Variable Name	Range	Descriptions/Source/Comments
U_Ind_Rate_In	I = Ind_Fuel_Source	
U_Ind_Rate_Out	I = Ind_Fuel_Source	
U_Ind_Relative_Percent	I = Ind_Fuel_Source	
U_Ind_Relative_Shares	D = Ind_Fuel_Source	
U_Ind_Relative_Slider	I = Ind_Fuel_Source	
U_Other_Fix_Shares	O = Other_Fuel_Source	
U_Other_Fuel_Share	O = Other_Fuel_Source	
U_Other_Not_Fix_Shares	O = Other_Fuel_Source	
U_Other_Rate_In	O = Other_Fuel_Source	
U_Other_Rate_Out	O = Other_Fuel_Source	
U_Other_Relative_Percent	O = Other_Fuel_Source	
U_Other_Relative_Shares	O = Other_Fuel_Source	
U_Other_Relative_Slider	O = Other_Fuel_Source	
U_Reactor_Fix_Shares	Reactor_Type	
U_Reactor_Not_Fix_Shares	Reactor_Type	
U_Reactor_Rate_In	Reactor_Type	
U_Reactor_Rate_Out	Reactor_Type	
U_Reactor_Relative_Percent	Reactor_Type	
U_Reactor_Relative_Percent_Total		
U_Reactor_Relative_Share	Reactor_Type	2000 IEO estimated share data from Table 18 pp. 104 in IEO 1999. 1999 IAEA MicroPris
U_Reactor_Relative_Shares	E = Reactor_Type	
U_Reactor_Relative_Slider	Reactor_Type	
U_Reactor_Shares_Percent_Total		
U_Tran_Fix_Shares	T = Tran_Fuel_Source	
U_Tran_Fuel_Share	T = Tran_Fuel_Source	
U_Tran_Not_Fix_Shares	T = Tran_Fuel_Source	
U_Tran_Rate_In	T = Tran_Fuel_Source	
U_Tran_Rate_Out	T = Tran_Fuel_Source	
U_Tran_Relative_Percent	T = Tran_Fuel_Source	
U_Tran_Relative_Shares	T = Tran_Fuel_Source	
U_Tran_Relative_Slider	T = Tran_Fuel_Source	
U3O8_Amt_C	R = Region, N = Reactor_Type	
U3O8_Amt_Region	R = Region	
UF6_Depleted_Amt_C	R = Region, N = Reactor_Type	
UF6_enriched_Amt_C	R = Region, N = Reactor_Type	
UF6_natural_Amt_C	R = Region, N = Reactor_Type	
UinORE_Amt_C	R = Region, N = Reactor_Type	
UinUO2_Amt_C	R = Region, N = Reactor_Type	

Model Variable Name	Range	Descriptions/Source/Comments
UMill_Tailings_Waste_Amt_C	R = Region, N = Reactor_Type	
Unassociated_HEU	R = Region	
Unburned_C_MOX_Proliferation_Cost		
Unburned_C_MOX_Proliferation_Index	Region	
Unburned_C_MOX_Security_Function	Region	
Unburned_C_MOX_Security_Parameter	Region	Effect of safeguards and security and material value.
Unburned_MOX	Region	Stock of commercial MOX produced and awaiting burning in a LWR.
Unburned_Reprocessed_U_Fuel	Region	Stock of unburned reprocessed U fuel. This stock should be used up each year. It is here mostly for symmetry with MOX. We assume no appreciable initial stock.
Unburned_wMOX	Region	Stock of MOX produced and awaiting burning in a LWR.
UO2_Amt_C	R = Region, N = Reactor_Type	
Uranium_Ore_Amt_C	R = Region, N = Reactor_Type	
Uranium_products_Generic		The Institute of Electrical Engineers at http://www.iee.org.uk/PAB/Env/nucfuelcycl.htm
Uranium_products_LWR		From UIC Australia. In spent fuel of 1000 kg the weights of U-235, U-238, U-236
Vitrified_FP	Region	Rate at which fission products are vitrified. The vitrification factor accounts for the mass added by the glass or ceramic.
Vitrified_wPu	Region	Rate at which vitrified Pu is produced
Waste_Rock_Amt_C	R = Region, N = Reactor_Type	
Weapon_Policy_Option	R = Region	
Weapon_Production	R = Region	
Weapon_Projection_Sample	R = Region	
Weapon_Projection_Sample_In	R = Region	
Weapon_Projection_Sample_Out	R = Region	
Weapon_Proliferation_Cost		
Weapon_Proliferation_Index	Region	
Weapon_Security_Function	Region	
Weapon_Security_Parameter	Region	Effect of safeguards and security and material value.
Weapons_2000	R = Region	
Weapons_Allowed_by_Treaty	R = Region	
Weapons_Dismantled	R = Region	www.brook.edu/FP/PROJECTS/Nucwcost/50.htm 50 Facts about US Nuclear Weapons
Weapons_HEU_to_Backend	R = Region	
Weapons_in_Active_Stockpile	R = Region	

Model Variable Name	Range	Descriptions/Source/Comments
Weapons_in_Reserve	R = Region	www.brook.edu/FP/PROJECTS/Nucwcost/50.htm 50 Facts about US Nuclear Weapons.
Weapons_Number_Treaty	R = Region	
Weapons_Policy	R = Region	
Weapons_Policy_Total		
Weapons_Production_Capability	R = Region	
Weapons_Production_Requirements	R = Region	
Weapons_Projection	R = Region	
Weapons_Pu_to_Backend	R = Region	
Weapons_Retired	R = Region	Notional unclassified value.
Weapons_Retired_Initial	R = Region	
Weapons_Target	R = Region	
Weapons_Target_China		
Weapons_Target_FSU		
Weapons_Target_OECD		
Weapons_Target_Previous	R = Region	
Weapons_Target_ROW		
Weapons_Target_USA		
Weapons_Total	R = Region	
WGpu_Proliferation_Cost		
WGPu_Proliferation_Index	Region	
WGPu_Security_Function	Region	
WGPu_Security_Parameter	Region	Effect of safeguards and security and material value.
WGPu_Separated	R = Region	
Wind_Damages	Region, Common Impacts	
Wind_Impact_1		
Wind_Impact_2		
Wind_Impact_3		
wMOX_Burn_Rate	Region	MOX burning is limited to approximately 1/3 of the fuel rods in a LWR. However, the current number of licensed reactors is small. This will be user defined. The default value could be the currently licensed amount (small) or the theoretical capacity of 1/3 total LWR burn rate (very large). Additionally, weapons MOX may be treated differently than commercial MOX. Until we get a number, we'll use a large default value. wMOX_Fab_Capacity
wMOX_Burning	Region	Tons of MOX burned per year. Burned MOX supplies energy, consumes Pu stocks, and produces spent MOX.
wMOX_Fab	Region	Russian and US capacity to produce MOX.

Model Variable Name	Range	Descriptions/Source/Comments
wMOX_Fab_Capacity	Region	Worldwide capacity to fabricate MOX from weapons Pu. In the U.S., the DOE is planning to build a facility to do this since there are no domestic commercial MOX facilities. Conversion of the pits into plutonium oxide for disposition could begin by 2005 and disposition of non-pit plutonium could begin about 2004, according to DOE. http://axil.whatswhat.com/nuke/html/us_russia_plutonium.html SpentFUEL, 3/29/99 (Vol. 5, No. 249): "U.S. DOE Awards $130 Million Pu Disposition Contract To Duke-COGEMA-Stone & Webster Team" The U.S. Department of Energy last week signed a contract to support disposition of surplus plutonium from dismantled warheads. DOE identified the Savannah River Site as the preferred site for the mixed oxide fuel fabrication facility. The European vendors are willing to build a fuel fabrication plant in Russia for the plutonium disposition project, but in this case, the problem is how to finance it. At a meeting of government plutonium experts in November 1996, a team comprised of COGEMA, Siemens, and Russia's Ministry of Atomic Energy (MINATOM) announced a three-phase plan for a fabrication plant. The feasibility and basic design phase would last from January to June1998, followed by construction and then operation by MINATOM. The plan is to build the facility and burn 1,300 kilograms of plutonium annually in five Russian reactors. http://axil.whatswhat.com/nuke/html/mox_russ.html Russian plant is expected to process 2 tons of wPu and US plant is expected to have similar capacity. http://www.uic.com.au/nip42.htm step function gives capacity for a Russian and a US plant. Have assumed that both plants capacities are the same (the size of the planned Russian plant). We can change this as more data becomes available. In the interim, the user can change the value with a slider.
wMOX_Fab_Rate	R = Region	Amount of wPu that is made into MOX.

Model Variable Name	Range	Descriptions/Source/Comments
wMOX_Factor		Tons of wMOX created for each ton of reprocessed Pu. wMOX is 5% Pu (assuming > 90% Pu-239): http://www.uic.com.au/nip42.htm
wMOX_Production	Region	Quantity of MOX produced per year from weapons Pu.
wMOX_Proliferation_Cost		
WMOX_Proliferation_Index	R = Region	
wMOX_Security_Function	Region	
wMOX_Security_Parameter	Region	Effect of safeguards and security and material value.
World_Carbon		
World_Damages_1		
World_Damages_2		
World_Damages_3		
World_Damages_4		
World_Electricity_Demand		
World_Fuel_Consumption_by_Fuel	F = Fuel_Share_Total	
World_Fuel_Consumption_by_Fuel_ Total		
World_Fuel_Consumption_by_Region	R = Region	
World_Fuel_Consumption_by_Region_ Total		
World_Fuel_Total		
World_O_and_Ind		
world_total_SF_to_repositories		
world_total_spent_wMOX_to_ repository		
World_Total_Surplus_WGPu		
world_total_vitrified_FP		
world_total_vitrified_wPu		
WorldTotal_Elect_Demand		
wPu_Awaiting_Disposal	Region	Stock of weapons Pu awaiting either disposal or conversion into MOX.
wPu_Awaiting_Processing	R = Region	
wPu_Destined_for_Vitrification	R = Region	Stocks of wPu awaiting vitrification build up here.
wPu_Destined_for_wMOX	Region	Stocks of wPu awaiting conversion to wMOX build up here.
wPu_Vitrification	Region	Pu will be mixed with fission products and vitrified. It is assumed that there are sufficient fission products from defense operations (which are not tracked in this model) to accomplish this task. Therefore, this vitrification process does not deplete the stock of fission products created in commercial reprocessing operations.

Model Variable Name	Range	Descriptions/Source/Comments
wPu_Vitrification_Capacity	Region	1.3 tons per year is based on a desire by DOE to process 13 tons total over ten years. Infor from Jim Marra (SRS).
wPu_Vitrification_Factor		Tons of vitrified Pu mixed with fission products created for each ton of non-vitrified wPu. The vitrification factor accounts for the mass added by the glass or ceramic and the fission products. "Depending on the technology utilized, studies indicate that immobilization can handle between 5 and 12 percent plutonium by weight." quote from CRS Report for Congress: Nuclear Weapons: Disposal Options for Surplus Weapons-Usable Plutonium May 22, 1997, Craig M. Johnson, Zachary S. Davis. They cite Department of Energy, Office of Fissile Materials Disposition, Technical Summary Report, 2-16. Loading factor = 10%. Phone conversation S. Conrad (SNL) to Jim Marra (SRS) on 8/16/2000
wPu_Vitrification_Rate	Region	Once the Savannah River vitrification plant develops the capability to vitrify Pu, then the vitrification rate will be the capacity of the plant.
Year_MRS_Opens	Region	
Year_of_Last_Production		
Year_Repository_Opens	Region, Repositories	Place holders.
year_to_transfer_Pu_from_FSU_to_USA		
year_to_transfer_SF_from_OECD_to_FSU		
Year_wPu_Vitrification_Online	Region	Expected start up date at SRS is 2008 according to J. Marra (SRS).

Appendix B.

Table B-1.1. Acronyms.

Acronyms	
α	curve shape factor
AI	Attractiveness Index
BCM	Billion cubic meters
BTU	British thermal unit
CANDU	Canadian deuterium reactor
China	People's Republic of China
Ci	Curies
CO_2	Carbon dioxide
DOE	U.S. Department of Energy
DOE/EIA/IEO	U.S. Department of Energy, Energy Information Administration, International Energy Outlook
EIA	Energy Information Administration
EM	Energy Module
FSU	Former Soviet Union
GDP	gross domestic product
Gen. IV	Generation IV
GEFM	Global Energy Futures Model
GWae	Gigawatts of annual electricity
GWe	gigawatts of electricity
GWh(e)	gigawatt hours of electricity
HEU	highly enriched uranium
HTGR	high-temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEO	International Energy Outlook
LWR	light-water reactor
MicroPRIS	Microcomputer Power Reactor Information System
MMT	million metric tons
MMTCE	Million metric tons coal equivalent
MOX	mixed-oxide fuel
MRS	monitored retrievable storage
NO	nitrous oxide
OECD	Organization for Economic Cooperation and Development
PI	Proliferation Index
Pu	plutonium
Q	quantity
RBMK	*reactor bol'shoy mozhnosti kanal'nyye* (Chernobyl design, lightwater reactor, graphite-moderated channel)

Acronyms	
RIPA	Risk Informed Proliferation Analysis
ROW	rest of the world
SI	Security Index
SNL	Sandia National Laboratories
SO_2	sulphur di-oxide
USA	United States of America
VOCs	volatile organic compounds
WG	weapons grade
WGPu	weapons grade plutonium
WISE	World Information Service on Energy

Distribution

1	MS-0724	Eagan, Bob, 6000
1	MS-0771	Berry, Dennis, 6800
1	MS-0736	Blejwas, Tom, 6400
1	MS-0701	Davies, Peter, 6100
1	MS-1375	Ellis, Dori, 5300
1	MS-0741	Tatro, Margie, 6200
2	MS-0749	Baker, Arnie, 6010
2	MS-0749	Malczynski, Len, 6010
1	MS-0451	Conrad, Steve, 6541
1	MS-0451	Beyeler, Walt, 6541
1	MS-0785	Harris, Dave , 516
1	MS-1371	Rexroth, P.A., 5326
1	MS-0748	Bixler, Nate, 6415
1	MS-1374	Mann, Greg, 5327
1	MS-0727	Sanders, Tom, 6406
1	MS-9018	Central Technical File, 8945-1
2	MS-0899	Technical Library, 9616
1	MS-0612	Review & Approval Desk, 9612 for DOE/OSTI